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Technical Progress Report for the Quarter
1 January — 31 March, 1981

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Office of Nuclear Waste Isolation

Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

ONWI
Office of Nuclear Waste Isolation

BATTELLE Project Management Division

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II

TABLE OF CONTENTS

Page

OVERVIEW 1

The ONWI Technical Program 1
Quarterly Highlights 6
Public Information Program 11

TECHNICAL PROGRESS REPORTS . . . .

WBS 1.1 Systems: Summary 14
1.1.2 Waste Isolation Program Evaluation Assistance 15
1.1.2 Disposal Charge Analysis 16
1.1.2 Systems Characteristics Analysis 17
1.1.2 Very Deep Hole Systems Decision Studies 18
1.1.3 Institutional Arrangements for Radioactive Waste Siting 19
1.1.4 Very Deep Hole Geosciences 20
1.1.4 Very Deep Hole (VDH) Systems Engineering Studies 22
1.1.5 Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) 24
1.1.5 Systematic Comprehensive Evaluation of Performance and Total Effectiveness of Repositories (SCEPTER) . . . 30
1.1.5 Analysis of Radionuclide Migration in Geologic Media 32
1.1.5 Modeling of Waste Form Leaching 35

WBS 1.2 Waste Package: Summary 37
1.2.1 Performance Measures Development 39
1.2.2 Spent Fuel Studies 40
1.2.2 Spent Fuel Disassembly Alternatives Impact 43
1.2.3 Salt-Brine-Waste-Canister Interactions 45
1.2.3 Desiccant Materials Screening 47
1.2.3 Development of Backfill Material 49
1.2.3 The Chemistry and Physics of Nuclear Waste-Rock Interactions 53
1.2.3 High-Level Waste Interactions 54
1.2.3 Container Barrier Development 57
1.2.3 Stabilizer Materials Program 59
1.2.3 NBS Independent Measurement Standards Laboratory 62
1.2.4 Repository Waste Package Design Studies 65
1.2.4 Design Specification Support 66
1.2.5 Waste Package Performance Evaluation 67
1.2.5 High-Level Waste Form Preparation (HLWFP) 69
1.2.5 Cooperative Field Tests in Salt 70
1.2.5 Thermal Gradient Brine Migration 72

WBS 1.3 Site: Summary 74
1.3.1 Site Baseline 77
1.3.2 Acoustic Studies in Climax Stock 78
1.3.2 Shale Structure Studies 80
1.3.2 Thermodynamic Properties of Actinides 82

TABLE OF CONTENTS
(Continued)

Page

1.3.2 Waste-Rock Interactions Technology (WRIT) Program 84
1.3.2 Uranium Disequilibrium Dating of Ground Water 87
1.3.2 Helium Dating of Ground Water 88
1.3.2 Osmotic Effects of Clay 89
1.3.2 Effects of Organics in Deep Ground Water 90
1.3.3 Geologic Project Manager Program--Salina Basin 93
1.3.3 Paradox Basin Geologic Exploration 94
1.3.3 Paradox Basin Studies 97
1.3.3 Permian Basin Geologic Studies 102
1.3.3 Geologic Project Manager (GPM) Program--Permian Basin 104
1.3.3 East Texas Salt Dome Studies 106
1.3.3 Gulf Coast Salt Dome Project 108
1.3.3 Louisiana Salt Dome Studies 109
1.3.3 Louisiana Hydrology 114
1.3.3 Mississippi Hydrology 115
1.3.3 Lake Superior Region Granitics 116
1.3.3 Data Compilation and Map Publication--Lake Superior Region (Minnesota) 117
1.3.5 Environmental Characterization 118
1.3.5 Lake Superior Regional Environmental Characterization 120
1.3.5 Regional Environmental Characterization Studies--Southern Appalachian Region 121
1.3.7 Study of Morro do Ferro 122
1.3.7 Hydrology of Nearly Impermeable Rock 127
1.3.7 Behavior of Natural Repositories 129

WBS 1.4 Repository: Summary 131
1.4.1 ONWI Support Program: Program Coordination and Special Problems 135
1.4.1 Expected Repository Environments in Granite (ERE-G) 137
1.4.2 Experiment Development to Support Field Testing 138
1.4.2 ONWI Support Program: Thermal Property Measurements 141
1.4.2 Bench Scale Salt Creep Tests, Phase III 143
1.4.2 Transient Creep in Rock Salt 145
1.4.2 Salt Model Pillar Studies 147
1.4.2 Strain-Related Radiation Damage Measurements in Rock Salt for Waste Disposal Applications 148
1.4.2 Radiation Chemistry of Salt Mine Brines and Hydrates 154
1.4.2 Long-Term Monitoring and Analysis of the Avery Island Heater Experiments 155
1.4.2 Rock Behavior Under Elevated Pressure and Temperature 157
1.4.2 Materials Properties and Stress Measurement Techniques 161

TABLE OF CONTENTS
(Continued)

Page

1.4.2 Swedish Cooperative Project 167
1.4.2 Stripa Testing Project 169
1.4.2 Heated Block Test in Granitic Gneiss 172
1.4.2 Crystalline Rock Mining Technology 176
1.4.3 NWTS Repository Equipment Development Plan 178
1.4.3 Equipment Reliability and Maintainability Methodology 180
1.4.4 Directional Antenna 182
1.4.4 Data Transmission Alternatives 184
1.4.4 Monitor for Detecting Nuclear Waste Leakage in a Subsurface Repository 186
1.4.4 Nuclear Quadrupole Resonance (NQR) Techniques to Measure Stress and Strain in Rocks 188
1.4.4 Stress Displacement Measurement Techniques 189
1.4.5 Repository Sealing Project 190
1.4.5 Borehole Plugging Program 192
1.4.5 Seal Materials Selection and Longevity 194
1.4.5 Seal Materials Performance Limits and Longevity 198
1.4.5 Wellbore Damage Zone Determination 200
1.4.6 Alternate Geologic Media Engineering Studies 202
1.4.6 A Study of Horizontal Emplacement in Salt 203
1.4.6 Technology Development Studies for Geologic Disposal: Effects of Earthquakes on Subsurface Facilities 204
1.4.6 Impacts of Defense Waste on Repository Design 205
1.4.8 Fractured Rock Studies Program 207
1.4.8 Stripa Data Analysis 211
1.4.8 Material Properties Testing and Analysis 213
1.4.8 Convective Heat Transfer in Room and Pillar Geometries 220
1.4.8 Convective Heat Transfer Within Spent Fuel Canisters 222
1.4.8 The Effects of Far-Field Inhomogeneities on Surface Temperature and Heat Transfer From a Repository 225
1.4.8 Development of ROCMAS (Thermo-Mechanical-Hydrological) Code 229
1.4.8 Boundary Element Model Development--Repository Design Studies 230
1.4.8 ONWI Support Program: Effects of Water in Salt Repositories 232
1.4.8 Analysis of Thermal/Mechanical/Hydrological Response of Rock 235
1.4.8 Analysis of Flow Through Fractured Crystalline Rock . . . 237

WBS 1.5 Regulatory and Institutional: Summary 239

WBS 1.6 Test Facilities and Excavations: Summary 240
1.6.1 Salt Test Facility Conceptual Design 242
1.6.2 Alternate Geology Test Facility--Mine Screen 244

ABBREVIATIONS 245

DISTRIBUTION LIST 249

OVERVIEW

by

Neal E. Carter
General Manager

THE ONWI TECHNICAL PROGRAM

This report describes the technical accomplishments during the period from January through March, 1981, on the commercial nuclear waste management programs under the direction of the Office of Nuclear Waste Isolation (ONWI).

The National Waste Terminal Storage program (NWTS) was established in 1976 and given the responsibility of developing a system for the permanent isolation of nuclear wastes. NWTS is part of the Office of Nuclear Waste Management in the U.S. Department of Energy. The establishment of NWTS signaled the acceleration of the national program.

The purpose of the NWTS program is to develop the technology and facilities required for the disposal of commercial spent nuclear fuel, defense high-level waste, and transuranic waste, ensuring public health and safety and protection of the environment. The program includes facilities for receiving, encapsulation, and disposal of wastes.

The scope of the NWTS repository development effort includes comprehensive geologic exploration, technology development, equipment testing, and model verification activities, as well as the design, licensing, construction, operation, and decommissioning activities required to provide geologic repositories and spent fuel handling and packaging facilities. Development of the technology, methodology, and facilities for interim spent fuel storage, waste treatment, and waste transportation, which are interfacing activities with the terminal isolation activity in the national waste management program, are being carried out in other DOE efforts.

ONWI has lead responsibilities in the NWTS structure for oversight and coordination of all programs, for development of the general technology, and for geologic exploration of non-DOE land. A project management group, ONWI directs and evaluates studies, research, and development performed by subcontractors on repository sites and designs.

The scope of ONWI activities includes providing the technology and facilities for the terminal isolation of these wastes by disposal in mined repositories deep underground in stable geologic formations. Steps leading to the accomplishment of that purpose include:

- Site exploration, characterization, and recommendation
- Design, licensing, construction, and operation of a commercial geologic repository (or repositories)
- Technology development to support these steps.

Throughout the process, ONWI has the responsibility to provide public information on all aspects of the program and to encourage public interaction.

It is recognized that safety of the public is the overriding program objective. The technical programs have been formulated to meet the challenge of the NRC licensing process, which is the institutional mechanism for assuring the public protection has been accomplished.

The ONWI program is organized into eight tasks, each one being a level-two element in the NWTS program standard Work Breakdown Structure (WBS).

WBS Element	Task Title
1.1	Systems
1.2	Waste Package
1.3	Site
1.4	Repository
1.5	Regulatory and Institutional
1.6	Test Facilities and Excavations
1.7	Land Acquisition
1.8	Program Management

The purpose of the Systems Task is to transform the statement of the ONWI mission into a set of objectives and requirements (the baseline) for the ONWI program and to allocate these to each of the remaining tasks. The Systems Task defines the overall strategies and alternatives that will be considered in proceeding toward the goal. It defines subsystems and their interfaces and develops the criteria to be used to determine whether the requirements of the subsystems have been met. It also provides an integrated assessment of the predicted system performance to assure that the overall system requirements have been met.

Conceptually, the geologic repository is viewed as a waste isolation system made up of three functionally distinct but interacting subsystems which provide multiple natural and man-made barriers to the release of the contained waste into the biosphere. The subsystems correspond to the first three tasks: the waste package, the site, and the repository (Figure 1).

The Waste Package Subsystem (or Task) is an important part of the overall waste disposal system. During the repository operational phase, the waste package provides safe containment for the waste material during handling and emplacement operations and helps ensure that the waste can be safely retrieved from the repository, if necessary.

In the long term, the waste package provides containment during the thermal period (the time the fission products are decaying), and provides redundant, long-term waste isolation capabilities beyond the thermal period. The waste package will include the waste form itself and a system of engineered barriers that may consist of filler material, a canister, and one or more layers of protective materials selected to minimize interactions among the waste, the host rock, and any ground water that might enter the repository.

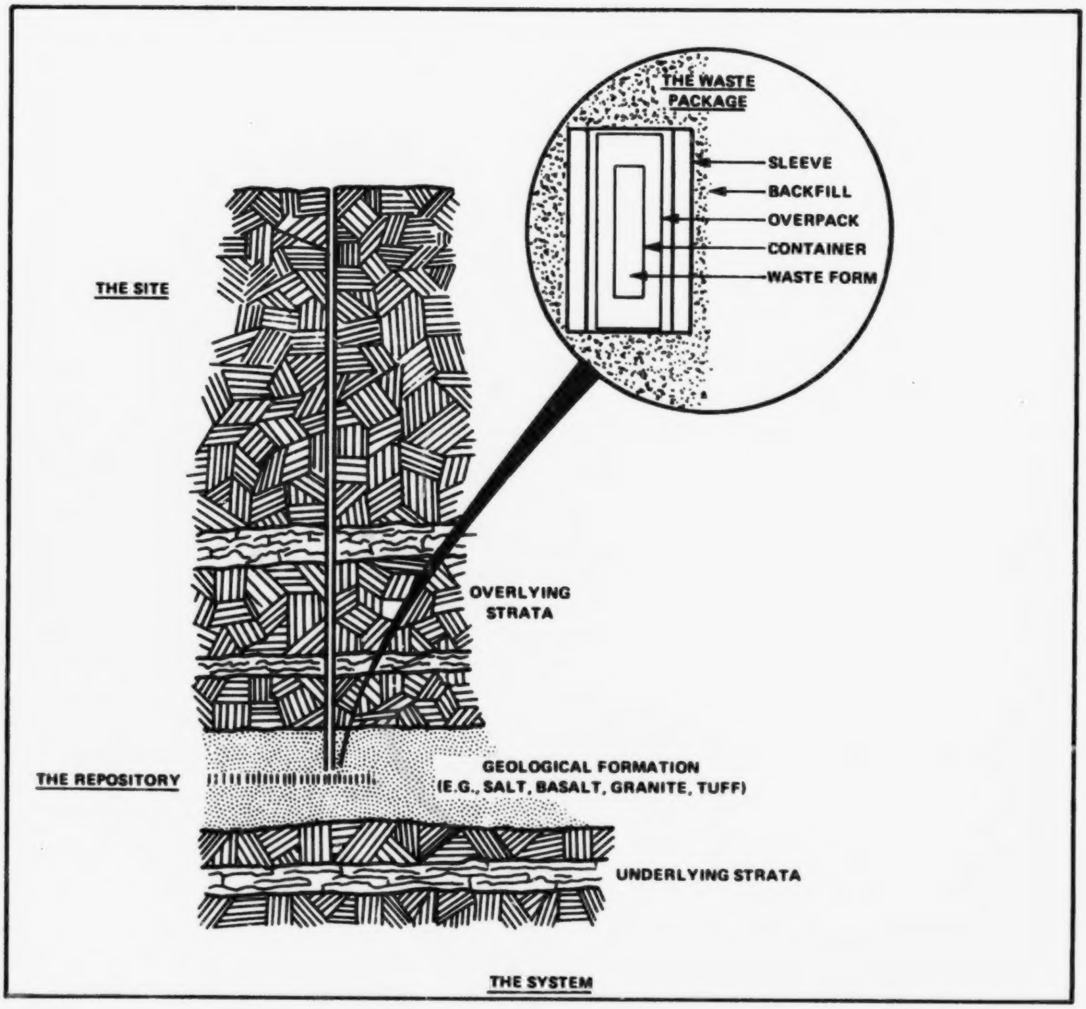
THE WASTE PACKAGE
SLEEVE
BACKFILL
OVERPACK
CONTAINER
WASTE FORM
THE SITE
OVERLYING STRATA
THE REPOSITORY
GEOLOGICAL FORMATION (E.G., SALT, BASALT, GRANITE, TUFF)
UNDERLYING STRATA
THE SYSTEM

Figure 1. Geologic Disposal System.

The Site Subsystem (or Task) includes natural barriers which provide waste containment and isolation. These barriers will keep radionuclides from reaching people in unacceptable quantities by (1) maintaining the waste in its emplaced position for a very long period of time (i.e., providing waste containment); (2) limiting radionuclide mobility through the geohydrologic environment to the biosphere (i.e., providing isolation); and (3) making inadvertent human intrusion difficult by locating the respository deep in a host rock. The site will contain a host rock suitable for construction of the repository and containment of the waste, as well as surrounding rock formations which can provide adequate isolation. The associated hydrologic system will exhibit low ground-water flow rates, long flow-path lengths to the biosphere, and evidence of long-term stability. The important natural attributes of the host rock will include its hydraulic and chemical characteristics, which determine ground-water flow rates and the dispersion rates of any dissolved waste products; and its thermal-mechanical characteristics, which determine the stability of the host rock to withstand the thermal effects produced by the decay of the fission products in HLW.

The Repository Subsystem (or Task) (Figure 2) will consist of the man-made structures that permit access to the underground facilities and enhance waste containment, and natural barriers, such as the local host rock, that provide containment and isolation after closure. The design, construction, and operation of the repository will be carried out in a manner that preserves the containment and isolation capabilities of the particular site. Surface facilities will provide for waste receipt, preparation of the waste for emplacement, and transfer of the waste to the underground workings. Repository facilities at depth will include a receiving area for transfer of waste packages to the emplacement holes and equipment to emplace auxiliary barriers, backfill, and other shielding.

The Regulatory and Institutional Task serves to obtain the regulatory, social, and political acceptance of the proposed repository system, without which the mission could not succeed. This task develops criteria that will assure protection of the public health and safety and the environment, and provides the documentation required by the NRC for its review and action before a license to construct is issued to DOE. Not only is public review of the proposed repository project a part of the licensing process, but the DOE has an extensive program to provide all data developed by the program to the public. In addition, under the provisions of the National Environmental Policy Act, all major actions contemplated by DOE will be documented and subject to public review.

The Test Facilities and Excavations Task provides facilities, both in the laboratory and in the field, required to provide physical data and verification of models to be used in design and licensing applications. The acquisition of test facilities requires long lead times, and their need must be justified far in advance of actual operation. Their use will extend beyond the technology phase, being required during design and the subsequent licensing process, to evaluate or demonstrate operability, safety, and reliability. The in situ field facilities allow an

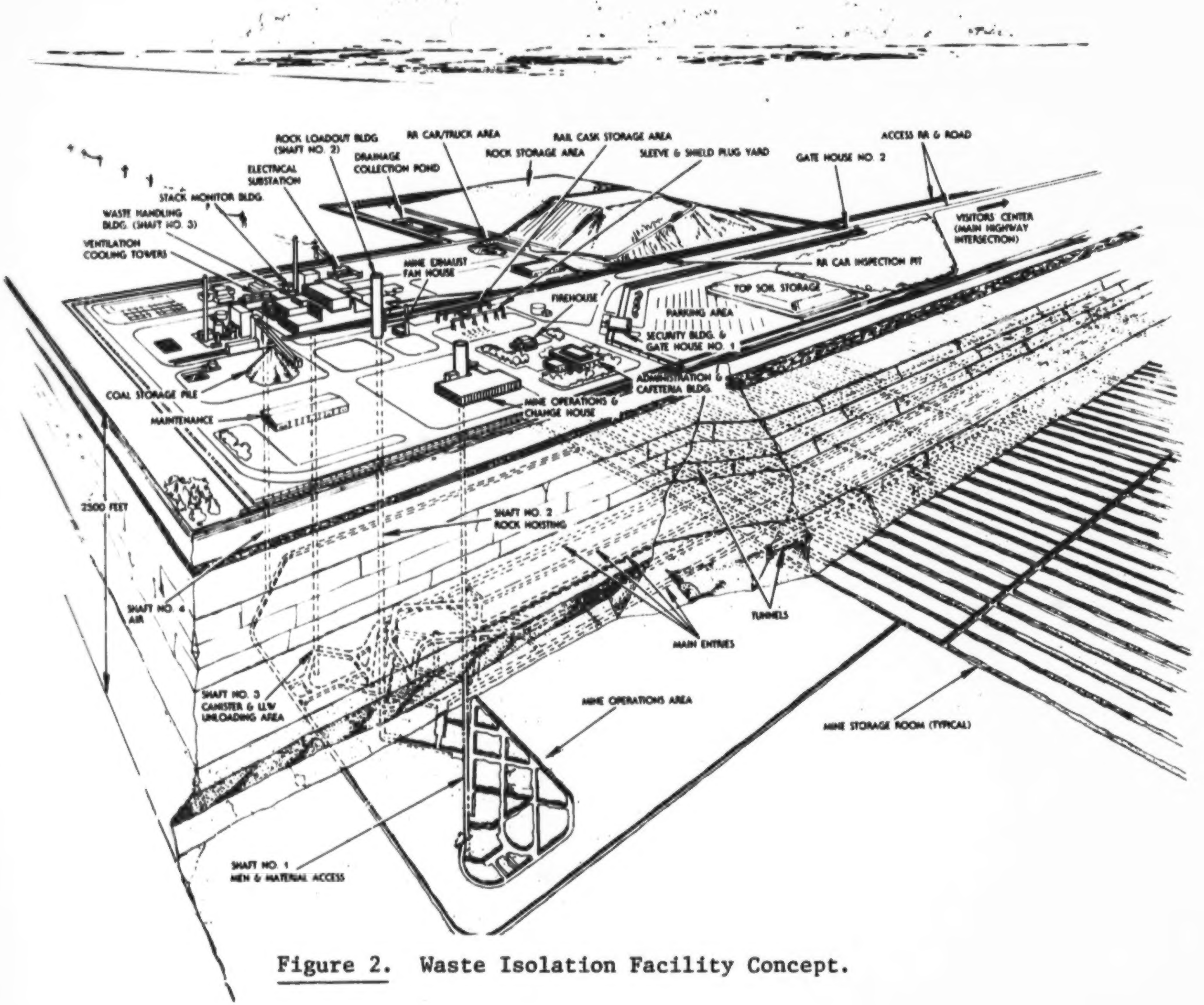
ROCK LOADOUT BLDG (SHAFT NO. 2)
RR CAR/TRUCK AREA
RAIL CASK STORAGE AREA
ACCESS RR & ROAD
DRAINAGE COLLECTION POND
ROCK STORAGE AREA
SLEEVE & SHIELD PLUG YARD
GATE HOUSE NO. 2
ELECTRICAL SUBSTATION
STACK MONITOR BLDG.
WASTE HANDLING BLDG. (SHAFT NO. 3)
VENTILATION COOLING TOWERS
VISITORS' CENTER (MAIN HIGHWAY INTERSECTION)
MINE EXHAUST FAN HOUSE
RR CAR INSPECTION PIT
TOP SOIL STORAGE
FIREHOUSE
PARKING AREA
SECURITY BLDG. & GATE HOUSE NO. 1
ADMINISTRATION & CAFETERIA BLDG.
COAL STORAGE PILE
MINE OPERATIONS & CHANGE HOUSE
MAINTENANCE
2300 FEET
SHAFT NO. 2 ROCK HOISTING
SHAFT NO. 4 AIR
TUNNELS
MAIN ENTRIES
SHAFT NO. 3 CANISTER & LLW UNLOADING AREA
MINE OPERATIONS AREA
MINE STORAGE ROOM (TYPICAL)
SHAFT NO. 1 MEN & MATERIAL ACCESS

Figure 2. Waste Isolation Facility Concept.

experimental integration of the repository subsystems in actual demonstrations of the interactions between the waste package, the repository, and the site.

The Land Acquisition Task will enable preferred sites to remain inviolate after they have been chosen and will see that proper legal procedures are followed in the acquisition process.

The programs required are enumerated in the Work Breakdown Structure (WBS) shown in Figure 3. Progress on various elements of this Work Breakdown Structure is reported in this Quarterly Report in accordance with the WBS elements.

QUARTERLY HIGHLIGHTS

Major accomplishments during this quarter are listed below.

SYSTEMS

- The data compilation for the repository cost model being developed by PNL is nearly complete.

- ORNL finished a report on fiscal interactions between local governments and federally owned waste isolation facilities, stressing the distinction between compensation and incentives. Their evaluation of the payment-in-lieu-of-taxes (PILOT) mechanism continued.

- Influences on design and cost of a very deep hole (VDH) system were identified by Woodward-Clyde Consultants in a draft report that also covered other aspects of a developed reference VDH system.

- A draft document was completed in the Very Deep Hole Geosciences project. The report addresses questions on mechanisms of borehole failure, state of stress, theoretical and experimental evidence for permeability reduction with depth, and geophysical inference for deep hydrologic properties.

WASTE PACKAGE

- Studies on spent fuel continued in the areas of waste form assessment, characterization, degradation, and disassembly alternatives impact. Five spent fuel waste forms were analyzed for relative in-repository performance.

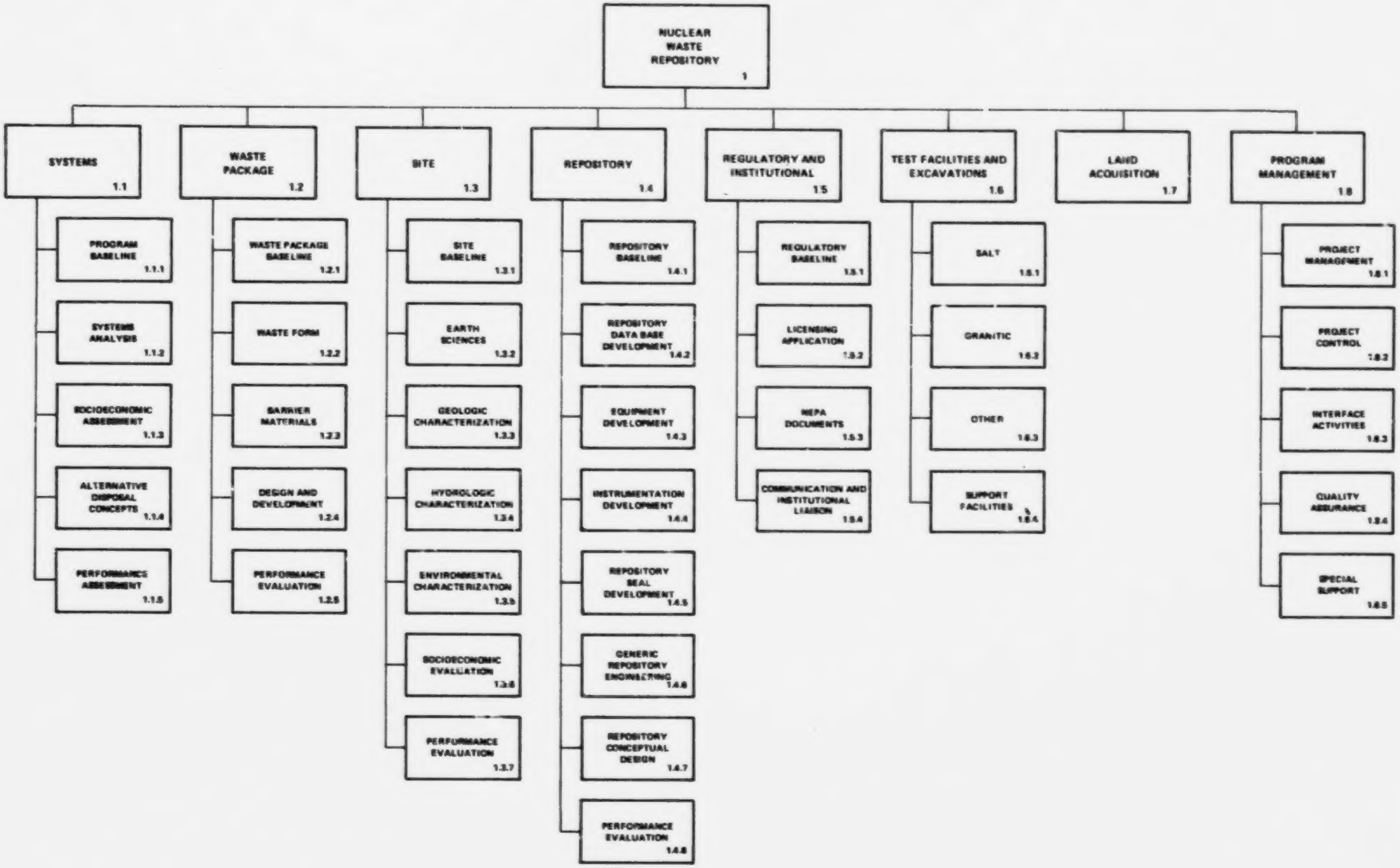
NUCLEAR WASTE REPOSITORY 1
SYSTEMS 1.1
PROGRAM BASELINE 1.1.1
SYSTEMS ANALYSIS 1.1.2
SOCIOECONOMIC ASSESSMENT 1.1.3
ALTERNATIVE DISPOSAL CONCEPTS 1.1.4
PERFORMANCE ASSESSMENT 1.1.5
WASTE PACKAGE 1.2
WASTE PACKAGE BASELINE 1.2.1
WASTE FORM 1.2.2
BARRIER MATERIALS 1.2.3
DESIGN AND DEVELOPMENT 1.2.4
PERFORMANCE EVALUATION 1.2.5
SITE 1.3
SITE BASELINE 1.3.1
EARTH SCIENCES 1.3.2
GEOLOGIC CHARACTERIZATION 1.3.3
HYDROLOGIC CHARACTERIZATION 1.3.4
ENVIRONMENTAL CHARACTERIZATION 1.3.5
SOCIOECONOMIC EVALUATION 1.3.6
PERFORMANCE EVALUATION 1.3.7
REPOSITORY 1.4
REPOSITORY BASELINE 1.4.1
REPOSITORY DATA BASE DEVELOPMENT 1.4.2
EQUIPMENT DEVELOPMENT 1.4.3
INSTRUMENTATION DEVELOPMENT 1.4.4
REPOSITORY SEAL DEVELOPMENT 1.4.5
GENERIC REPOSITORY ENGINEERING 1.4.6
REPOSITORY CONCEPTUAL DESIGN 1.4.7
PERFORMANCE EVALUATION 1.4.8
REGULATORY AND INSTITUTIONAL 1.5
REGULATORY BASELINE 1.5.1
LICENSING APPLICATION 1.5.2
NEPA DOCUMENTS 1.5.3
COMMUNICATION AND INSTITUTIONAL LIAISON 1.5.4
TEST FACILITIES AND EXCAVATIONS 1.6
SALT 1.6.1
GRANITIC 1.6.2
OTHER 1.6.3
SUPPORT FACILITIES 1.6.4
LAND ACQUISITION 1.7
PROGRAM MANAGEMENT 1.8
PROJECT MANAGEMENT 1.8.1
PROJECT CONTROL 1.8.2
INTERFACE ACTIVITIES 1.8.3
QUALITY ASSURANCE 1.8.4
SPECIAL SUPPORT 1.8.5

Figure 3. ONWI Work Breakdown Structure.

- Candidate barrier element materials are being evaluated by means of corrosion screening tests, using Hanford (basaltic) ground water at 250 C. Corrosion screening of a variety of nickel, iron, copper, titanium, and zirconium base alloys in simulated Hanford ground water was completed.

- The spent fuel stabilizer fill process screening test was also completed. This test measured the interaction of candidate metal stabilizers with LWR fuel cladding during stabilizer emplacement at elevated temperatures.

- Several activities for high-level waste interactions were reported this quarter. Work has started on the time-temperature transformation behavior of TiCode-12 and Ti-50A titanium samples. Possible alternative overpack materials to TiCode-12 have been selected. The first PNL-Sandia joint HLW package interactions test was completed, sampled, and disassembled. Work is continuing on the general corrosion of titanium alloys to establish corrosion mechanisms and screening studies for effective anion getters in brine. Specimens of TiCode-12 were successfully charged with hydrogen from a gaseous environment.

- The draft report, "Engineered Waste Package Conceptual Design: Defense High Level Waste (Form 1) Disposal in Salt", was submitted for review. The report discusses waste package conceptual design studies for Form Number I of defense high-level waste (Savannah River) in a salt geological formation.

SITE

- The final Regional Environmental Characterization Report was issued for the Paradox Basin. Draft reports on the recommendation of study areas and environmental area studies were issued for public comment. Bechtel prepared reports on the environmental evaluation of Utah area studies and on water availability in southern Utah, and work on the transportation access study continued.

- The Texas Bureau of Economic Geology completed a topical report on the regional dissolution of Permian salt in the West Texas Panhandle. Stone and Webster Engineering Corporation completed a preliminary draft Subregional Geological Characterization Report that identifies several large areas in the Palo Duro basin suitable for future detailed investigations.

- In the Gulf Coast Salt Dome Region, the hydrology of the three salt dome basins and individual salt domes is being studied. This work is extremely important in determining the future hydrologic stability of the domes.

- Research into the Near Dome and Deep Basin Hydrology continues. The timing of the dome growth cycles in the East Texas Basin is being investigated.

- The final Regional Environmental Characterization Report and the final Regional Summary Report were issued for the Gulf Coast Salt Dome Region. Work began on the Site Characterization Plan.

- The regional environmental literature survey in the Minnesota portion of the Lake Superior Region was completed, and a preliminary draft report was prepared.

- Approval was received from DOE to initiate regional literature searches in the Northeast Region: New York, Pennsylvania, Massachusetts, Connecticut, New Hampshire, and Maine; and in all five Southeast Region states: Maryland, Virginia, North Carolina, South Carolina, and Georgia.

- Leach tests conducted by WRIT program have shown that dissolution kinetics is strongly dependent on glass composition as well as pH. Fluid composition also strongly affects leaching rate with bicarbonate solutions and has the strongest effect for all radionuclides except technetium.

- It was found that the water in streams draining the Morro do Ferro deposit in Brazil and the surrounding terrain all have high concentrations of total thorium, with the highest concentration found for the stream draining the thorium deposit. Filtered samples from the stream draining the deposit have over a ten-fold higher concentration of thorium than do the other samples.

REPOSITORY

- The post-test evaluation of the Site A and Site B heater tests at Avery Island was initiated. Plans were made to terminate the heating and moisture collection at the Site NB (natural brine) brine movement experiment; a brine inflow model was developed; the two accelerated borehole closure experiments were discontinued; and the extended permeability measurement experiments were concluded.

- In the radiation damage to rock studies, radiation damage measurements have been made on a large variety of natural rock salt samples to determine if the radiation damage characteristics of natural rock salt are dependent on the geological origin of the salt or vary among horizons at the same site.

- The major granitic formations in the United States were evaluated for geologic characteristics, such as depth and lateral extent, tectonic stability, seismicity and faulting, and natural resources.

- Measurements of rock-mass modulus of deformation (Er) at the CSM experimental mine using the NX-CSM cell were completed during the quarter. In addition, significant progress was made in developing a computer program to analyze the fracture data from core logging, in-hole petroscope logging, and structural mapping.

- Final documentation of the field results obtained from the Swedish American Cooperative project continued. The data base resulting from fracture mapping and core logging in the full-scale heater experiment drift is available as a computer-based listing of individual fractures. Compilation of the records of ground water infiltrating into heater and instrumentation boreholes during the operation of the three heater experiments is also complete.

- In the fractured rock studies program, the Charcoal Black Granite specimens, reduced to 0.764 m in diameter and 1.52 m in height, was received at LBL. A series of falling head radial flow tests was conducted on the main fracture to get an idea of the conductivity of the fracture, in order to choose proper instrumentation to measure the flow rate during the subsequent steady-state radial flow tests.

- The Bell Canyon Test Summary Report, which discusses an in situ evaluation of the ability of a cement grout plug to seal boreholes, is complete.

- Work in the seal materials performance limits and longevity program focused on completing examinations of ERDA-10 grouts; examining five laboratory grouts aged 4 years and 1-year-old Bell Canyon Test specimens; continuing dynamic tests and compressive strength tests of those grouts; collecting and testing Class H high sulfate-resistant cements; and analyzing data through 90 days for grouts made to optimize BCT-1FF.

- Laboratory experiments were continued to obtain experimental data on the wellbore damage zone caused by full-scale drilling operations. The plug flow test was successfully completed, and laboratory permeability measurements on anhydrite have continued.

- The equipment reliability, availability, and maintainability (RAM) program has been completed, and a report was written.

- The final design of the major components of the nuclear quadrupole resonance spectrometer has been completed, and a high-power transmitter output component has been assembled.

REGULATORY AND INSTITUTIONAL NEEDS

- The third Licensing-Interface Control Group meeting was held in Columbus on January 28-29. Comments on the draft Licensing Plan were reviewed and incorporated, and the plan was approved.

- Proposals from candidate Licensing Project Manager groups were received and evaluated by the Site Selection Board. Initial screening was completed, and site visits were conducted during the report period.

- The initial summary reports on consultation activities for the 21 states in which ONWI is managing NWTS activities were transmitted to DOE for review. States covered in these reports are Louisiana, Mississippi, Texas, Utah, Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Georgia, Maryland, North Carolina, South Carolina, Virginia, Michigan, Minnesota, and Wisconsin.

TEST FACILITIES AND EXCAVATIONS

- All major facilities and systems designs for a salt test facility conceptual design project were developed during this quarter.

MAJOR PUBLIC INFORMATION EVENTS OF THE QUARTER

ONWI continued its extensive activities in support of the consultation process throughout the quarter. Materials and staff support also were made available for briefings in Maine, New Jersey, New Hampshire, Utah, Mississippi, and Louisiana.

Three proposals related to audiovisual presentations were submitted to NPO. One of the proposals is to develop a 10-to-15-minute technical film on deep underground mining to facilitate public understanding of the isolation conditions within a geologic repository. The second is to produce a multi-image slide and tape presentation on repository site selection processes for use, particularly in providing information to residents of areas where there are NWTS activities. The third proposal relates to revising the current multi-image slide and tape presentation to bring it up to date. Anticipating release and national distribution of the film during the second quarter of 1981, final editing was completed on the NWTS film, Nuclear Waste Isolation: A Progress Report.

A paper on Consultation and Concurrence: A Status Report was presented at the ANS Waste Management 1981 meeting in Tucson, Arizona. Members of the Communications and Government Liaison staff also participated in Atomic Industrial Forum workshops in Phoenix, Arizona (February 22-26) and Durham, North Carolina (February 8-11).

ONWI had several significant exhibits:

February 12-16, Northern Panhandle Energy Expo '81, Wheeling, WV
March 9-11, Eighth Energy Technology Conference and Exposition, Washington, DC
March 13-15, Southern California Energy Conference, Laguna Hills, CA
March 15-17, North-Central California Energy Conference, Fresno, CA
March 18-20, Geological Society of America, Southern Section, Hattiesburg, MS.

In addition, there were showings of the two-projector multi-image presentation in a variety of events such as the following:

Meetings of the American Nuclear Society in Washington, DC, and Alhambra and San Diego, CA
Meetings of civic and classroom groups in Columbus and Delaware, OH and Lawrenceville, NJ
Several public meetings in the Grand Junction, CO, area.

ONWI also furnished information on the NWTS program to a number of professional journalists and others who are working on books and major articles related to nuclear waste disposal, including the following: Kenneth W. Meckstroth of The Columbus Dispatch, David Crisp of the Palestine (TX) Herald Press, Luther Carter of Science Magazine, Fred Shapiro of The New Yorker, and Mike Lafferty of the Associated Press.

MAJOR REPORTS PUBLISHED DURING THE QUARTER

LBL-11477/SAC-29	Thermal and Thermomechanical Data from In Situ Heater Experiments at Stripa, Sweden
ONWI-104	Creep of 50-mm Diameter Specimens of Dome Salt from Avery Island, Louisiana
ONWI-107	Use of K-Ar Dating and Oxygen Isotopes for Determining the Thermal History of Shales
ONWI-190(1)	Avery Island Heater Tests: Temperature Measurements for the First 300 Days
PNL-3302	Relationships of Dispersive Mass Transport and Stochastic Convective Flow Through Hydrologic Systems
PNL-3708	Further Glaciological Considerations in Selection of Original Sites
SAND 80-1375	Bell Canyon Test Summary Report
UCRL-53128	Thermal Properties of Avery Island Rock Salt to 573 K and 50 MPa Confining Pressure
UCRL-85191	Thermal Properties of Rock Salt and Quartz Monzonite to 573 K and 50 MPa Confining Pressure
UCRL-85285	The Effect of Pressure and Temperature on the Thermal Properties of a Salt and a Quartz Monzonite
UCRL-85515	Design Criteria for Laboratory Measurements of Low Permeability Rocks
UCRL-85784	An Apparatus for Determining the Thermal Properties of Large Geological Samples at Pressures to 0.2 GPa and at Temperatures to 750 K.

TECHNICAL PROGRESS REPORTS

In this section the progress reports of the programs in the various waste management technologies are presented according to the organization of the Work Breakdown Structure (WBS). Each report carries a WBS number for the convenience of the reader. The content of the second level of the WBS follows:

WBS 1.1 Systems. These reports deal with systems analysis, socio-economic assessment, alternative disposal concepts, and performance assessment.

WBS 1.2 Waste Package. These reports consist of studies on performance measures, waste forms, barrier materials, the design and testing of waste packages, and performance evaluation through modeling, demonstration testing, and natural experiments.

WBS 1.3 Site. These reports deal with the earth sciences of geophysics, geochemistry, and transport properties, and with geologic, hydrologic, and environmental characterization of sites that provide natural barriers in salt, granite, and shale.

WBS 1.4 Repository. The repository reports involve studies to build a data base; equipment, instrument, and seal development; repository engineering and conceptual design; and performance evaluation.

WBS 1.5 Regulatory and Institutional. The work reported in this area concerns the regulatory, social, and political acceptance of the proposed repository system.

WBS 1.6 Test Facilities and Excavations. This area is concerned with facilities in both salt and alternative media which will eventually be used for laboratory and in situ testing of the relationships among the package, repository, and site.

SUMMARY

1.1 SYSTEMS

The scope of the Systems Task covers the systems analyses, socioeconomic assessments, and performance assessments of the entire waste isolation system. Also covered in this task are investigations of alternative disposal concepts for nuclear waste disposal. The prime objective of this task is to identify the options available to resolve the problems of waste isolation and to make suitable choices among the alternatives by broad ranging, multidisciplinary analyses.

Much of the work performed in systems analysis, socioeconomic analysis, and alternative concepts was related to cost studies. The data compilation for the repository cost model, being performed by PNL, is nearly complete. ORNL finished the report on fiscal interactions between local governments and federally owned waste isolation facilities, stressing the distinction between compensation and incentives. Their evaluation of the payment-in-lieu-of-taxes (PILOT) mechanism continued. Influences on the design and cost of a very deep hole (VDH) system were identified by Woodward-Clyde Consultants in a draft report that also covered other aspects of a developed reference VDH system.

Work in performance analysis included detailed outlines of modeling and analysis progress.

PNL continued collecting data on repositories in different media and nearly completed the work for salt (Disposal Charge Analysis project). Concurrent development of the repository cost model continues.

The conclusion that communities will require financial incentives, as well as compensation, for repository siting was reached in a report completed by ORNL as part of a study on fiscal interactions between local governments and federally owned waste isolation facilities. Ongoing financial studies in this project (Institutional Arrangements for Radioactive Waste Siting) include the possible application of payments-in-lieu-of-taxes mechanisms.

A draft document was completed in the Very Deep Hole Geosciences project. The report addresses questions on the mechanisms of borehole failure, state of stress, theoretical and experimental evidence for permeability reduction with depth, and geophysical inferences for deep hydrologic properties. New work for the quarter was the assembly of laboratory equipment to develop a method of monitoring the volume of a fracture undergoing deformation.

In the performance analysis area, work on three mathematical modeling and analyses projects continued. A new project, Modeling of Waste Form Leaching (University of Illinois), has been undertaken to develop and verify a model to calculate the probable leach rate of nuclear waste forms by aqueous solutions. Two technical results for situations where network dissolution is negligible and flow rates are large are discussed.

WBS 1.1.2

PROJECT: Waste Isolation Program Evaluation Assistance

PRINCIPAL INVESTIGATOR: Lawrence Livermore Laboratory (R. C. Maninger)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objective of this project is to enhance the ONWI capability for NWTS program planning. Specifically, the project shall:

- Design a methodology for representing the planned structure of the research and development activities and results of the NWTS program.
- Develop a methodology for coalescing the data being generated by the NWTS program and presenting the results in a form most useful to decision makers.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.1.2

PROJECT: Disposal Charge Analysis

PRINCIPAL INVESTIGATOR: Battelle Pacific Northwest Laboratories (L. L. Clark)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objective of this program is to determine the sensitivity of the disposal charge, including that of defense wastes, to geologic and institutional factors.

PROGRESS REPORTED PREVIOUSLY

This project began June, 1980, with an analysis of the impact on disposal charges of storing defense wastes in commercial spent fuel repositories. During the last quarter, the effect of various institutional factors on charges was analyzed and data collection was initiated for an analysis of the effect of repository media on disposal costs.

ACTIVITIES DURING THE REPORTING PERIOD

During this quarter, the search for data on repository design, operation, and costs was expanded and nearly completed. Extensive data have been compiled for repositories in salt. Less information is available for repositories in granite, basalt, and tuff.

The information collected above will be used as input to a repository cost model which is under concurrent development. This model will be used to analyze the effect of package types, repository size, thermal loading, and other variables on overall disposal costs in each media. Currently, the basic core of the model has been outlined and the associated inputs and outputs have been programmed. The model is being constructed in a modular fashion so that new repository designs can be analyzed with little or no reprogramming.

FUTURE ACTIVITIES

During the next quarter the cost model will be completed and exercised using the available data on each repository medium. The most favorable sets of conditions in terms of cost will be identified for each medium.

WBS 1.1.2

PROJECT: Systems Characteristics Analysis

PRINCIPAL INVESTIGATOR: Lawrence Livermore Laboratory (W. G. Sutcliffe)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objective of this project is to develop information on how the uncertainties about engineered and natural systems affect the uncertainty of long-term performance for nuclear waste repositories. The purpose for developing this information is to provide background information which ONWI can use in formulating R&D plans. This work provides a systems analysis perspective.

The primary objective is to identify the uncertainties dominating the uncertainty about the performance of a system. In particular, the conditions under which various subsystems and parameters dominate will be identified. Also, the potential differences between waste forms, geologic media, and site characteristics and how these differences affect the assessed performance of the system will be considered.

The scope of the work has been limited to postclosure analysis of nuclear waste migration via ground-water flow.

ACTIVITIES DURING THE REPORTING PERIOD

A draft report was submitted to ONWI in March.

WBS 1.1.2

PROJECT: Very Deep Hole Systems Decision Studies

PRINCIPAL INVESTIGATOR: SRI International
(F. L. Offensend)

ONWI PROJECT MANAGER: R. E. Best

OBJECTIVE

The objective of this project is to develop a pilot decision model for use in managing the Very Deep Hole research program. The model is to be demonstrated with a preliminary evaluation of selected research strategies, including a preliminary comparison of the very deep hole (VDH) concept with the mined geologic repository (MGR). The expectation is that many of the planning principles developed for the VDH program will be transferable to other R&D programs within ONWI.

ACTIVITIES DURING THE REPORTING PERIOD

The project was completed during the reporting period. A final report was submitted for review and approval.

WBS 1.1.3

PROJECT: Institutional Arrangements for Radioactive Waste Siting

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (E. Peelle)

ONWI PROJECT MANAGER: J. R. Finley

OBJECTIVE

The objective of this work is to assess the impacts of nuclear waste isolation facilities on local and state host areas and to design siting arrangements which are acceptable to local interests. The design and testing of possible incentive arrangements for siting a hazardous waste facility must, therefore, include an integration of the economic, institutional, and public participation factors into each alternative considered.

The goal is to develop a range of evaluated options to include in the consultation and concurrence and other siting processes including incentives; compensation mechanisms for risk, damages, and long-term land commitment; state and local participation; local verification and monitoring; and mediated negotiation.

PROGRESS REPORTED PREVIOUSLY

Beginning in the last quarter of FY 80, an evaluation was made of the payments-in-lieu-of-taxes (PILOT) mechanism for three atomic communities and its possible application to nuclear waste disposal siting. This work is continuing, as is the more general review of existing institutional arrangements and incentives for siting waste handling facilities.

The report on fiscal interactions between local governments and federally owned waste isolation facilities has been completed. This analysis of transfer payments from a federally owned facility to the local government affected by the facility stresses the distinction between the compensation of costs and the provision of incentives. Unless a community can be shown to reach a higher level of satisfaction, under a rather strict interpretation of satisfaction, it will have no incentive to encourage the siting of a facility, whether or not the direct costs associated with the facility are compensated. Despite this fact, it should be possible to design an intergovernmental revenue system that does provide incentives.

ACTIVITIES DURING THE REPORTING PERIOD

Work continues on the impact of the PILOT mechanism. Wide variations in local government service levels and revenue systems preclude accurately forecasting the local fiscal impacts of a nuclear waste disposal facility. This work attempts to place bounds on the ranges of these impacts and relates these impacts to changes in the user fees that would be necessary to finance local services.

WBS 1.1.4

PROJECT: Very Deep Hole Geosciences

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (LBL) (L. Cohen and T. Doe)

ONWI PROJECT MANAGER: R. E. Best

OBJECTIVE

The FY 80 project was aimed at further review and assessment of geological, hydrological, and geochemical uncertainties to improve the state of knowledge and provide bases for a program to define and develop the very deep hole (VDH) waste disposal alternative.

The FY 81 objectives are to (1) investigate the question of fracture closure with depth, (2) determine what mechanisms contribute to borehole failure at depth, and (3) begin developing numerical models of heating, stress, and fluid flow around a deep hole repository.

PROGRESS PREVIOUSLY REPORTED

This project began in FY 80. Previous progress consisted of initiating the study of fracture closure and borehole failure.

ACTIVITIES DURING THE REPORTING PERIOD

Literature Review Document

A draft document, Geologic Feasibility of Disposal of Radioactive Wastes in Very Deep Holes--Literature Review, was submitted to ONWI in early February. The 354-page document contains chapters on rock mechanics, hydrogeology of deep hole environments, geochemistry of deep hole environments, and geophysical inferences on properties of rocks at potential deep hole repository depths. Some of the major questions addressed include the mechanisms of borehole failure, state of stress, theoretical and experimental evidence for permeability reduction with depth, and geophysical inferences for deep hydrologic properties.

Borehole Failure Studies

Work began on the laboratory simulation of borehole failure under stress. A variety of sand and plaster mixtures are being tested to simulate, at low temperatures and pressures, the behavior of rocks at deep hole conditions. Equipment for monitoring borehole volumes and for injecting resin penetrants into the fractures formed around the boreholes has been designed and is in fabrication. When complete, the samples containing the boreholes will be subjected to a range of biaxial load combinations, after which the samples will be sectioned and the resulting fractures will be mapped.

Fracture Closure at High Temperatures and Pressures

The main activity during the quarter has been assembling the equipment for the laboratory work, specifically, developing a method for monitoring the volume of a fracture undergoing deformation. The method of monitoring deformation is shown in Figure 1 and consists of recording the level of mercury in a pipette which is connected to the mercury-filled fracture. By monitoring the total displacement between the ends of the sample as well as monitoring the mercury level, one can obtain a relationship between the fracture void volume and the normal deformation as a function of normal stress. During this quarter, the system has been tested under room temperature and atmospheric pressure conditions.

Although the ultimate goal is to study fracture closure under deep hole temperature and pressure conditions, tests of the equipment on a sample of Stripa granite have provided some interesting results over several loading cycles. Figure 2 shows the normal deformation of a single tensile fracture and its volume change over three loading

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cycles. The data are nonlinear as the fracture closes.

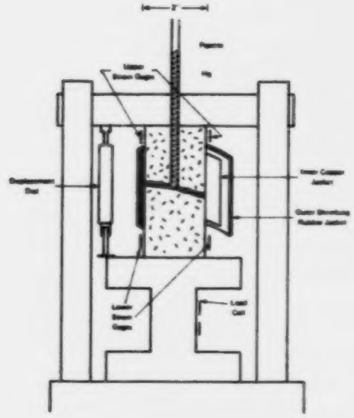

Figure 1. Setup of Experiment.

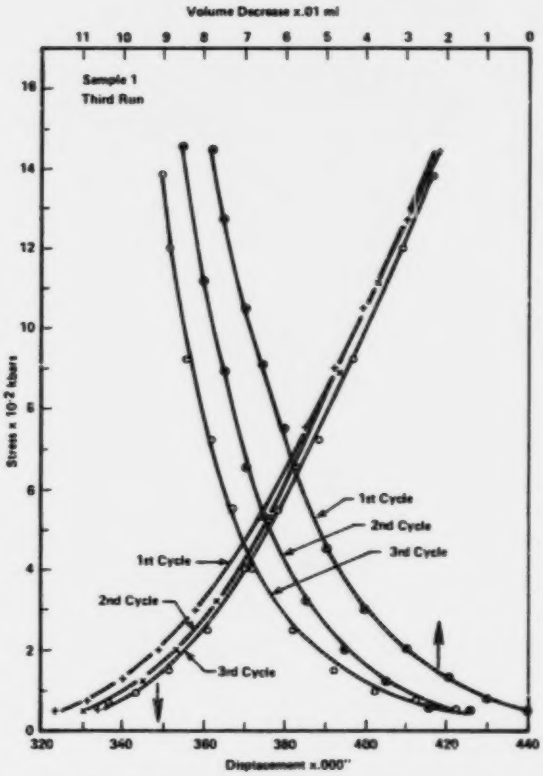

Figure 2. Fracture Volume Decrease and Normal Displacement as a Function of Normal Stress (Volume decrease values are shown circled; displacement values are uncircled).

The following preliminary conclusions have been made based on the work so far:

- The relationship between fracture volume reduction and normal displacement follows a parabolic curve (Figure 3); the lower rate of volume decrease at higher normal load suggests an expansion of the contact area of the asperities.
- Most irrecoverable fracture volume change occurs in the first load cycle (Figure 3).
- There may be some fracture volume increase with load caused by growth of new cracks; this was shown in one test (no figure presented here) where there was a sudden unaccounted for drop in the mercury level at high normal load.

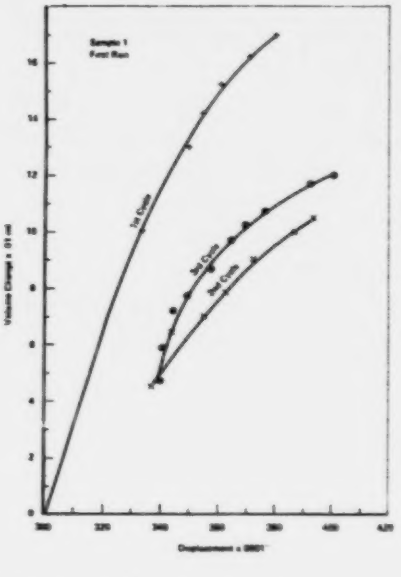

Figure 3. Fracture Volume Decrease as a Function of Normal Displacement.

FUTURE ACTIVITIES

Fracture deformation tests on salt and granite at high temperature and pressure will begin. Fabrication of the equipment for the borehole failure studies will be completed, and tests will be started. Modeling activities will start in June.

WBS 1.1.4

PROJECT: Very Deep Hole (VDH) Systems Engineering Studies

PRINCIPAL INVESTIGATOR: Woodward-Clyde Consultants (C. L. Taylor)

ONWI PROJECT MANAGER: R. E. Best

OBJECTIVE

The objective is to perform a planning study for the very deep hole disposal concept which will identify the significant problem areas, identify and discuss attributes of the VDH disposal concept, narrow discussions to a reference VDH concept, produce preliminary cost estimates, provide a program plan for VDH facilities and equipment development, and provide a rationale for additional work by ONWI if such work is warranted.

PROGRESS REPORTED PREVIOUSLY

Work was initiated 1 July 1980. The work to date has included a review of previous VDH studies, current drilling technology, and conditions likely to be found in deep geologic environments. Preliminary generic performance, safety, and design criteria were then developed, including criteria necessary to establish minimum and maximum depths. A VDH reference system was then selected to be used in the study.

Various VDH schemes were identified and evaluated for advantages and disadvantages. Based on this evaluation, the reference VDH system envisioned for this study consists of an array of rotary drilled holes to depths of 6,000 meters within a granite host rock. The waste canisters would be placed in a modified casing package and lowered as stacked units into an uncased emplacement zone 3,000 meters in height. Following emplacement, each stack would be grouted in place. The borehole would then be sealed above the emplacement zone. For the VDH system it was decided to redefine the geometry of containment to include the repository emplacement zone, while not precluding containment within the waste package.

ACTIVITIES DURING THE REPORTING PERIOD

The design and costs of the VDH system are influenced by (1) the ability to drill vertical holes with a high degree of accuracy; (2) the amount of casing and mud that need to be left in holes between drilling and emplacement activity (possibly for several years); and (3) the time sequence and distance between drilled holes and active drilling, emplacement holes and active drilling, and sealed holes and active drilling. Based on these considerations, the present reference system proposes to use large enough hole spacing to allow emplacement immediately after drilling, rather than closer hole spacing which would require a high degree of drilling accuracy and might result in a lapse of several years between the active drilling of a hole and emplacement of the waste.

The VDH concept, as envisioned, should achieve the goal of effective isolation of radionuclides from the environment in a safe, environmentally acceptable manner. However, the VDH concept does not lend itself to retrievability. If retrievability is required, the VDH concept is probably neither technically feasible nor economical.

Containment, as used in the VDH concept, refers to confinement in the repository zone rather than in the waste package. If containment is required within the VDH waste package, the VDH concept is probably technically feasible but will require a significant cost increase.

The reference-type VDH system is considered feasible, practical, logical, and achievable with slight development of present technology by the year 2000. The capital and operating costs for the reference VDH system are comparable to those of the mined geologic repository (MGR) assuming nonretrievability and limited (2 to 5 years) containment within the waste canister. The VDH R&D cost is low compared with other R&D costs in the NWTS program, because the envisioned VDH sytem makes maximum use of technology transfer for the work being performed for the MGR.

A draft report was prepared describing the study, the VDH reference system, preliminary costs and schedules, and an engineering program plan.

FUTURE ACTIVITIES

The draft report will be revised and submitted to ONWI.

WBS 1.1.5

PROJECT: Assessment of Effectiveness of Geologic Isolation Systems (AEGIS)

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (F. H. Dove)

ONWI PROJECT MANAGER: G. E. Raines

INTRODUCTION

The overall objectives of the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) program are to: (1) develop the capabilities needed to assess the postclosure safety of geologic repositories; (2) demonstrate the assessment capabilities by performing analyses of reference sites; (3) apply the assessment methodology to assist the National Waste Terminal Storage Program in site selection and waste package and repository design; and (4) perform repository site analyses responsive to the time schedule and to the level of sophistication required to meet the licensing needs of the National Waste Terminal Storage Program.

METHODOLOGY DEVELOPMENT

OBJECTIVE

The objectives are to provide improved methods for the mathematical modeling of ground-water hydrologic systems and the transport of contaminants, including radionuclides in subsurface systems. The improved methods are needed both as analytical tools during design of a waste repository and for long-term safety assessment, because they will assure that the most effective, advanced, and best evaluation capability is available to apply in analyzing waste repositories in deep geologic media.

PROGRESS REPORTED PREVIOUSLY

The concise, closed-form mathematical description of the flow field in a fractured porous material involving a single fracture was completed. Exact solutions were achieved to fracture intersections occurring at 90 degrees or at any angle which can be represented as the quotient of two integers. An approximate analytic solution for two intersecting fractures meeting at any angle was also derived. These results provide the foundation for a simulation capability yielding a concise description of the response of very complicated fracture systems.

Study was initiated toward developing a ground-water flow with uncertainty capability. The Keller smoothing method was applied to unsteady ground-water flows. The final form of the equation was more complicated than in the previous transport case.

Solutions to both the expectation and the variance of the one-dimensional contaminant transport problem became feasible. Also, significant alteration in the numerical procedure allowed for all terms of the analysis to be included for simple geometrics in two dimensions. Geostatistics were being applied to determine the drift and covariance structure of hydraulic conductivity and ground-water potential as input to the two-dimensional stochastic convective contaminant transport code.

The geohydrologic response functions summarize the overall contaminant inflow-outflow relationship for a particular subsurface repository and associated geohydrologic system. The problem will provide the optimal repository location within a ground-water system under constraints of satisfying ground-water flow, boundary conditions, and minimal impact upon the biosphere.

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ACTIVITIES DURING THE REPORTING PERIOD

Flow Methodology Development

Two approaches to the numerical solution of the inverse problem for hydraulic conductivity have been pursued. When used in sequence, these give a promising tool for calculating conductivities with minimal requirements on data smoothness. They include a path integral technique, which yields a global picture of the conductivity surface, and a variational algorithm, which gives more refined local results.

Two approaches to the stochastic analysis of ground-water flow are currently being examined. First-generation simulation codes are being developed to test Keller smoothing and Taylor expansion approaches to perturbations on the hydraulic conductivity and boundary conditions. Keller smoothing, developed for and applied to contaminant transport, has been extended to fluid flow and is implemented by the finite-element technique. This generates large arrays of stochastic quantities that must be subsequently manipulated by codes which are being developed. The Taylor series approach to fluid flow was transformed into a stochastic simulation code to characterize a steady-state ground-water potential distribution for a two-dimensional (e.g., horizontal) region.

The computer code for analyzing the basic underlying flow principles in a complex fractured permeable material has been debugged and tested. It considers flow as a superposition of the singularity analytical solutions for single fractures and intersecting fractures in a permeable matrix. Using analytical results, a very complete and detailed analysis of flow through and between complex fracture systems of specific statistical fracture lengths, apertures, and configurations can be considered.

The primary purpose in the analytical singularity approach solved by the code is to gain greater understanding of the pecularities of fracture flow and its more realistic description. Results to date, though preliminary, suggest some important characteristics of flow through fracture systems that may have been overlooked or certainly not emphasized in the past.

Flow through fractured materials, though having earlier first arrival times when compared to flow through porous media, have longer time intervals between the first and final arrival fronts. First results suggest that the advantage of the longer time between first and final fluid arrival may often more than compensate for the seeming disadvantage of earlier first arrival times in fracture flow. More study will be required to evaluate this effect, but the code already provides significant insight into such fracture flow characteristics.

Transport Methodology Development

The geostatistical modeling of ground-water pore velocity within a region of the Hanford reservation was completed. This involved the geostatistical estimation (Kriging) of effective porosity, hydraulic conductivity, and potential (head) gradients and the propagation of Kriging errors through pore velocity calculations to characterize the pore velocity estimating error. Geostatistical modeling is currently involved with supplying realistic (Hanford reservation) input to the stochastic flow and transport models in the methodology development tasks.

To check the stochastic transport model under development, a two-dimensional analytic solution was calculated and is being encoded to become part of a testing procedure for the results of transport under uncertainty.

The dispersive effects analysis indicates that the flow velocity autocovariance function is the fundamental statistical basis of the methodology. Application of a hydrologic system's velocity autocovariance function in conjunction with the stochastic convective flow equation results in a transport equation describing the expected solute concentration distribution. Autocovariance functions associated with field scale velocity variations result in transport equations different from the classical convection-dispersion equation based on a dispersion coefficient representation. But the convection-dispersion equation is known to provide a valid description of solute transport in laboratory scale soil column tracer experiments. These results suggest a need to reconcile the descriptions of transport in the transition from macroscopic scale to megascopic field scale. The current column tracer experimental analysis relates macroscopic scale statistical properties to standard measurements of hydrodynamic dispersion based on a dispersion coefficient.

Geohydrologic response functions were used as a contamination measure in an optimization procedure yielding optimal repository locations as an output. This methodology is founded on a view of the contaminant migration problem as a distributed parameter control system. Applying this procedure results in the selection of mitigation and control strategies satisfying these criteria: (1) ground-water flow and transport equations, (2) boundary constraints, and (3) minimization of contamination outflow and related measures.

The controls, or design parameters, are the repository location coordinates and repository geometry. In particular, Powell's (1969) Nonlinear Conjugate Direction Minimization algorithm was adapted to solve the case where contaminant addition does not change the flow field, employing an analytic potential function. Several test optimizations with favorable results were conducted assuming a square configuration for the deposition area. Bounding penalty functions were adjusted to provide a more efficient means to limit acceptable deposition regions. The results were subsequently plotted to show the relationship of the optimal trajectory to a reduction in quantity and arrival time maximum values.

FUTURE ACTIVITIES

The path integral method will be numerically implemented and tested in the hydraulic conductivity inverse problem. A variety of interpolants (piecewise constant, piecewise continuous, first derivative continuous, and second derivative continuous) for heads and conductivities will be used. The unknowns will be the coefficients to the conductivity interpolant. Two approaches being pursued for flow analysis under uncertainty will be further developed and used to analyze a well-characterized region within the Hanford reservation. Other work will include (1) developing the detailed geostatistics necessary to describe the hydrologic input, (2) completing the triple matrix product algorithm, (3) developing an analogous matrix-matrix-vector stochastic product, and (4) making initial comparisons of deterministic and stochastic solutions for the selected region.

Emphasis on fracture flow analysis will be upon documenting results obtained to present. A formal report will include the detailed mathematical derivations for the single fracture in a permeable material and the two intersecting fractures of varying size, length, and interaction angle. It will also show results from incorporating many such fractures into the overall fractured system. A second report will describe the computer code and its use in evaluating specific two-dimensional fracture flow systems.

A geostatistical analysis of the hydrologic field test data from the Borden, Canada hazardous waste disposal site is planned. These data contain direct ground-water velocity measurements which may be used as input to stochastic contaminant transport codes. A two-dimensional analytic solution will be used to verify the correctness of the codes.

Work will begin on incorporating the experimental data from the Hanford site into the two-dimensional code. The response-control approach to repository location using geohydrologic response functions as contamination measures will be refined and expanded to include flow sources and sinks.

SITE APPLICATIONS

PROGRESS REPORTED PREVIOUSLY

The Geologic Simulation Model (GSM) for basalt was essentially completed, and results of several hundred Monte Carlo-mode simulations were used for logic checkout and debugging. Adaptation of the GSM to analysis of salt anticlines of the Paradox Basin was initiated, as were studies of fault-plane permeability and crustal stress-strain. These studies will increase the flexibility of the GSM and improve its internal submodels.

Potential radiation doses at one million years after disposal of spent reactor fuel in a salt dome were calculated for a revised list of radionuclide content, with no significant differences from previous calculations. The DITTY1 code for calculation of population doses integrated over ten thousand years was completed and debugged. Dose analyses were performed for evaluation of EPA Draft HLW Criteria.

ACTIVITIES DURING THE REPORTING PERIOD

The Basalt Reference Site Initial Assessment (RSIA) draft report was prepared.

Scenario Analysis

The GSM was used in the Monte Carlo mode to generate a 200-simulation analysis to include in the Basalt RSIA draft report. The analysis was preliminary because the input data have not been adjusted so that GSM submodels behave in accordance with observed behavior of the real geologic systems. The simulations helped delineate areas that still need attention and gave some useful but not quantitatively reliable results.

The results indicate that near-repository faulting events, whether by extension of existing faults or creation of new ones over geologic time, dominate disruptive processes affecting the repository. This result is only valid at present for the first 10,000 years or so after closure because the Continental Glaciation Submodel does not yet reproduce the effects of past glaciations, let alone predict the behavior of future ones, and the Hydrology Submodel has not been modified to reflect calibrations of the regional (VTT) and Pasco Basin (FE3DGW) hydrologic models. Modifications to input data for the GSM submodels are in progress for future simulations, but the ones already exercised do not have realistic behavior in the areas of glacially enhanced or blocked recharge, glacially induced rock fracturing, Missoula flood effects, and overall ground-water flow rates. However, effects of glaciation will probably not be important for the next 10,000 years, so the present GSM results are qualitatively reasonable for that period.

Hydrogeologic and Transport Analysis

Hydrologic and transport analysis and computer modeling efforts for the Basalt RSIA were completed and documented. The hydrologic efforts consisted of a regional model of the Columbia River Basalts covering approximately 21,000 square miles in southeastern Washington.

The VTT multilayer two-dimensional code was used to model the regional system as three layers, with the surface layer consisting of the alluvial systems, the rivers, the lakes and the basalt seepage faces. The second layer consisted of the combined Saddle Mountains and Wanapum basalt system of aquifers. The third consisted of the Grande Ronde system of aquifers. Each layer contained a 55 x 55 finite-difference grid with a 3-mile grid spacing. Each layer was connected via an interlayer transfer coefficient.

Potentiometric data on over 350 Saddle Mountains and Wanapum basalt wells and an interpreted potentiometric surface for the Saddle Mountains-Wanapum system of aquifers were used during calibration to adjust transmissivity and interlayer transfer coefficient values to obtain a match between model-predicted and observed or interpreted potentials for the Saddle Mountains-Wanapum system of aquifers.

Estimates indicated $\sim$1,700,000 acre ft (AF)/yr of recharge to the basalt systems over the area of the regional model. Pumping withdrawal estimates amounted to approximately 204,000 AF/yr. In the calibrated regional model, the average transmissivity of a Saddle Mountains-Wanapum model node was 85,000 gal/day/ft, and 51,000 gal/day/ft for a Grande Ronde node. Vertical hydraulic conductivity in the basalts was on the order of 0.001 ft/day.

After developing and calibrating the regional model, a more detailed model of essentially the Pasco Basin area was developed. The regional model provided boundary conditions as input to the local model because a good deal of the flow in the local (or Pasco) basin area has it origin in the regional system and enters the local system through the northern and eastern boundary of the local model area.

The FE3DGW code was used in the local modeling. Several sources were used to prepare structural, transmissivity, and potential interpretations for the alluvial aquifer systems within the Pasco Basin and the Saddle Mountains, Wanapum, and Grande Ronde aquifer systems.

In addition, a joint recharge calculation effort, of the kind undertaken for the regional system but in more detail, was undertaken for the Pasco Basin area. All of these data were used in the detailed Pasco Basin model, which consisted of 606 surface nodes connected to form 555 surface elements. The input data on structures and potentials were used to infer the extent of the saturated zones in each of the four layers within the local model, and only saturated elements in each of the layers were modeled. The model area was approximately 1,870 square miles.

Recharge estimates within the Pasco Basin for prehuman conditions amounted to approximately 55,000 AF/yr, while estimates for current conditions amount to 287,000 AF/yr, with pumping withdrawal estimates on the order of 27,000 AF/yr.

Various sensitivity studies were carried out during calibration of the local modeling effort.

After the model was calibrated, it was used to predict travel times to the biosphere discharge point. Data from the hydrologic modeling effort and the scenario analysis task, along with water chemistry data and data on distribution coefficients, were then used to provide input to the transport modeling effort. Only the base case fault intersection event was examined with all transport model input parameters set at best estimate values. Transport results were analyzed on three different time frames: 1,000 yr, 10,000 yr, and the long-term 2,000,000 yr.

Dose Analysis

The DITTY1 code was again debugged and used to calculate population doses from five scenarios applied to an HLW repository. Two were completed: (1) direct consumption of the entire allowable release by a single person, and (2) contamination of wells at the site boundary with about 200 persons consuming contaminated water and irrigated foods. The latter scenario was, however, rerun with the newly debugged DITTY1 code.

The three new scenarios were based on a Hanford-type site, with the released quantities of each radionuclide being diluted in a simulated river, assuming a flow rate of 10^5 cubic ft/s. In the first of the three scenarios, the nuclides were released to the river uniformly over the 10^4-yr period; in the second, they were released uniformly over the first 10^3 years; and in the third, they were released over the last 10^3 years.

The results of the direct ingestion and well scenarios are not much different than reported previously. The direct ingestion case leads to upper bound, large numbers of health effects, 10^3 to 10^5 per 10,000 years. The results of the well water case match the EPA criteria of 10 health effects better than the other four scenarios studied. The three Hanford scenarios lead to a very small number of health effects (10^{-2} to 10^{+1}).

FUTURE ACTIVITIES

Input data for the GSM will be finalized and eventually published. The major, 1,000-simulation Monte Carlo runs will be performed and analyzed. Data gathering and conceptualization efforts for GSM application to the Paradox Basin and/or NTS will be stepped up as work on the Columbia Plateau winds down.

The GSM statistical package will be modified as experience is gained in analyzing data from the Monte Carlo simulations. These modifications will enhance the speed of analysis by (1) enabling interactive access to history file data for sorted simulations, and (2) making more meaningful summaries of the vast amount of data that the GSM generates.

In dose analysis, work will continue on documenting the DITTY1 code and evaluation of EPA documentation received from ONWI will begin.

WBS 1.1.5

PROJECT: Systematic Comprehensive Evaluation of Performance and Total Effectiveness of Repositories (SCEPTER)

PRINCIPAL INVESTIGATOR: INTERA Environmental Consultants, Inc. (R. B. Lantz)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

The objective of this program is to integrate, develop, and apply modeling technology to evaluate the effectiveness of a nuclear waste isolation system in preventing adverse radiological effects to present and future human beings and their environment. The technology will be used to support technology development, site evaluation, repository design, waste package design, and qualification and licensing activities of the NWTS program.

PROGRESS REPORTED PREVIOUSLY

The SCEPTER contract began in January, 1980. Work during the first three quarters concentrated on three fundamental areas: (1) program planning, (2) defining the scope of the modeling technology required to support the NWTS program, and (3) reviewing and evaluating the available technology. Through these activities, details of the program were structured, models that needed to be acquired or developed were identified, and integration concepts were defined. In the far-field task, selected geosphere, biosphere, and far-field state models were acquired, converted, and integrated, and they have undergone initial operational testing. In the near-field task (repository and waste package), acquisition and conversion of selected models have begun.

In addition, the first development activity under the SCEPTER program is proceeding: the development of a dual porosity-discrete fracture flow model. The first application activity for the SCEPTER modeling technology was identified: an independent assessment of the LLL and LASL hydrology and nuclide migration tests at the Nevada Test Site.

ACTIVITIES DURING THE REPORTING PERIOD

Most important to the SCEPTER program at this stage are the acquisition, conversion, integration, and operational testing of existing model technology. Specific progress during the quarter includes the following. The Far-Field State Model (pilot version from the PNL Geologic Simulation Model) was executed on SCEPTER computers; the results compared favorably with PNL-generated results. The tested version included new input and output modules. Draft documentation was prepared for the converted model. Verification testing of candidate geosphere and biosphere models was initiated, and selected near-field models have been acquired, converted, and implemented on the SCEPTER computer. Verification testing of the near-field models has also begun.

The modeling technology definition activities have been expanded to greater levels of detail. Draft performance specifications have been developed that explicitly relate specifications to modeling applications and define the detailed input-output interfaces of all models. The report on these detailed performance specifications is nearing completion.

The report, SCEPTER Review and Evaluation of Existing Models Useful for Waste Isolation Performance Assessment, was completed, constituting culmination of the second technical subtask.

The development of a ground-water flow model for fractured media continued on schedule. The flow model, which includes flow in discrete fractures and a dual-porosity representation of

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flow in the continuum between major fractures, is completed and tested. Documentation is being prepared.

The first application of SCEPTER's modeling technology was accomplished. Pretest calculations in support of the LLL hydrology tests in the NTS Climax granite were conducted, and a report was submitted to LLL. Hydrologic test data were received and analyses begun to define fracture parameters and other hydrological effects.

Initial steps were taken to define specific approaches for incorporating uncertainties into the SCEPTER modeling structure.

Development of contributions to the NWTS Performance Assessment Plan continued. Initial drafts of some sections were completed and submitted for comment.

FUTURE ACTIVITIES

Activities scheduled for the next quarter include completion of (1) Detailed Performance Specifications, (2) Contributions to the NWTS Performance Assessment Plan, (3) hydrology test data analysis, and (4) documentation of groundwater flow model for fractured media; and continuation of progress toward having far-field and near-field modeling technology operational and tested by October, 1981 and documented by December, 1981.

WBS 1.1.5

PROJECT: Analysis of Radionuclide Migration in Geologic Media

PRINCIPAL INVESTIGATOR: University of California at Berkeley (T. H. Pigford)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

The objectives are to develop analytical solutions and to make diagnostic calculations of the migration of radionuclides through geologic media. The exact results of these calculations can be used as benchmark checks against numerical computer codes. The solutions are used to predict the space-time-dependent concentrations of radionuclide chains as they migrate through geologic media and to make diagnostic calculations of the effects of phenomena not previously considered or not previously well understood in the modeling of radionuclide transport.

PROGRESS REPORTED PREVIOUSLY

The details of progress for FY 80 appear in the report Migration of Radionuclides through Sorbing Media: Analytical Solutions--II, LBL-11616. This report is now being issued.

The final report for FY 79, Migration of Radionuclides through Sorbing Media: Analytical Solutions--I, LBL-10500, which contains much of the basic mathematical foundation for the work, is now in final production.

ACTIVITIES DURING THE REPORTING PERIOD

Migration of Radionuclides Through Fractured Rock

When ground water permeates through fractures and fissures in rock, the migration of dissolved radionuclides may be retarded in part by the convection and diffusion into and out of crevices and micropores which are not the principal conductive paths for ground-water flow. Delays from transport into and out of the micropores can act as dispersive phenomena which broaden and attenuate the chromatographic bands of transported radionuclides. Sorption of radionuclides on surfaces within the micropores can retard the transport of radionuclides in the direction of ground-water flow.

Analytical solutions have been developed for the space-time-dependent concentration of radionuclides that consider constant one-dimensional ground-water flow in linear fissures, convection and diffusion of dissolved radionuclides into and out of micropores orthogonal to the main flow fissures, and local sorption equilibrium within the micropores. Sorption on surfaces other than in the micropores is neglected. The solutions are generalized in a recursive form for a radionuclide decay chain of arbitrary length.

For the case of no flow of water in the micropores, the concentration $N_1(z,t)$ of a radionuclide with no precursors, from a step-function release at $z = 0$, is given by

$$N_1(z,t) = N_1^0(t) e^{-\lambda t} \operatorname{erfc} \frac{B}{\sqrt{t-z/v}} \, h\left(t - \frac{z}{v}\right) \qquad (1)$$

with $$B \equiv \frac{z\varepsilon\sqrt{D/K}}{bv} , \qquad (2)$$

where z = distance normal to the plane source

v = ground-water velocity within the fissure

$N^o(t)$ = concentration at $t = 0$

D = diffusion coefficient

K = retardation coefficient for the radionuclide within the micropore

b = width of the fissure

ε = effective porosity due to micropores, and

h = Heaviside step function.

These equations are similar to those proposed by Neretnieks (1980), whose solutions have been limited to a radionuclide with no precursor and with no convective transport in the micropores.

The time-dependent diffusive flux, $J_i(z,t)$ of nuclide i at the entrance to a micropore at position z along the fissure, can be approximated as the separable product of a function $g_i(t)$ and the concentration $N_i(z,t)$ in the fissure

$$J_i(z,t) = g_i(t)N_i(z,t)$$

A generalized explicit solution for $N_i(z,t)$ then follows. The exact and approximate results have been programmed and demonstrated for the first member of a decay chain.

These analyses have been extended to include the effect of some ground-water flow through the transverse micropores, as well as through the main fissures.

The time for diffusion into and out of the micropores can reduce the time in which the radionuclides are in the proximity of sorption sites within the micropores. Consequently, the assumption of local sorptive equilibria within the micropores may not be valid. To examine the effects of radionuclide transport controlled only by diffusion into and out of micropores, with no local sorption in the micropores, general solutions have been developed for long-lived radionuclides which undergo negligible decay while within the micropores.

The analyses have been extended to the case of a plane source of finite extent, simulating a finite array of waste emplaced in a repository. Molecular diffusion of radionuclides within the fissures, transverse to the direction of ground-water flow, reduces the peak concentration of radionuclides in the ground water.

The above analyses are applicable to the planning and interpretation of experiments on radionuclide transport in fractured media.

Migration of Radionuclides in Two-Dimensional Flow Fields

A computer program has been developed to explore the analytical solution for the migration of radionuclide chains of arbitrary length in two-dimensional ground-water flow fields. The assumptions made in the analysis are as follows:

1. The hydrological ground-water flow is of the Darcy type and is time-independent.
2. Dispersion effects on the nuclide transport are neglected.
3. Sorption reactions are in equilibrium.
4. Media properties characterizing soil, water, and geochemistry are treated as isotropic and constant.

The program UCBNE21 yields the spatial distribution of the concentration of any member of an actinide chain at any time after the beginning of leaching. In this program, the two-dimensional hydrological potential is specified by an arbitrary number of point sources and sinks located in the field. The analytical-numerical superposition allows the construction of flow fields of a very diverse character. At present the program output is limited to evaluating nuclide concentrations at discrete field points, but the program is being extended to produce contour maps (isopleths) as well as three-dimensional surface views of the spatial distributions at fixed times.

In an alternative approach, the flow field is being constructed from field measurements of the hydrological potential at different field locations. The construction of the potential function for a benchmark example has been verified, but the computations of the velocity field need improvements. The ultimate aim of this second approach is to obtain a method to apply the analytical work to actual hydrological field data.

Boundary Layer Effects on Dissolution of Waste in Ground Water

The analysis of the dissolution of waste has been continuing. In the first model (completed), which is based on the solubility-limited concentration of a diffusing species such as silica, the transport from the cylinder takes place by molecular diffusion into a stationary surrounding liquid. The thickness of the concentration layer in which the concentration decreases to 10 percent of its surface value has been determined. An analytical method is being developed to describe the shrinkage of the waste form (or barrier) during the dissolution.

In a second analytical model, the influence of forced convection by a Darcy flow on the dissolution process is being studied in the presence of molecular diffusion. The flow is normal to the major axis of the cylinder. The numerical evaluation of the resulting solution is being started. It will be used for benchmark purposes. In parallel with this effort, analytical approximations to the solution are being investigated. The purpose of this analysis is to study the effects of the convection and to compare it with the pure diffusion model.

FUTURE ACTIVITIES

The modeling of dissolution kinetics as affected by the liquid boundary layer will continue, and the results will be used to compare conditions of laboratory leaching experiments to the longer term repository conditions. The effect of thermal convection upon the local flow field adjacent to dissolving waste, and the effects upon the dissolution boundary layer and dissolution rate, are also to be considered. When data on the planning of in situ experiments on radionuclide migration become available, the theoretical analyses will be used to predict the range of phenomena that can be expected. Application of the analytical solutions for radionuclide migration in two-dimensional flow fields will continue.

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WBS 1.1.5

PROJECT: Modeling of Waste Form Leaching

PRINCIPAL INVESTIGATOR: University of Illinois (A. J. Machiels)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this work is to develop and verify a model to calculate the probable leach rates of nuclear waste forms by aqueous solutions. The model integrates available experimental data into a mathematical formulation representing the fundamental physicochemical processes involved in waste form leaching. This approach is taken because long-term leaching behaviors must be extrapolated from experiments conducted for periods of time which are short relative to the time of interest.

When the events and processes which could lead to a failure of geologic containment are reviewed, it is generally concluded that the most probable failure mechanisms would result in ingress of circulating ground water into the repository, leading to leaching of the waste and migration of radionuclides with ground water. The understanding of leaching behaviors of waste forms is therefore required in order to evaluate waste package concepts.

PROGRESS REPORTED PREVIOUSLY

The project was started on 6 January, 1981. This is the first quarterly technical progress report.

ACTIVITIES DURING THE REPORTING PERIOD

A generic leach model is proposed, based on the applicability of:

1. Fick's law to describe the time and space-dependent concentrations of radionuclides in the solid waste form as they diffuse to the outer surfaces contracted by the water.
2. Chemical kinetics rate equations to describe the exchange processes occurring at the leachant - solid waste form interface between species absorbed on the waste form and in solution.

The model assumes that the release of any given species from the solid waste form to the leachant solution proceeds by a series of steps, the last one being a surface process. A one-dimensional geometry has been adopted for simplicity. The model is illustrated in Figure 1.

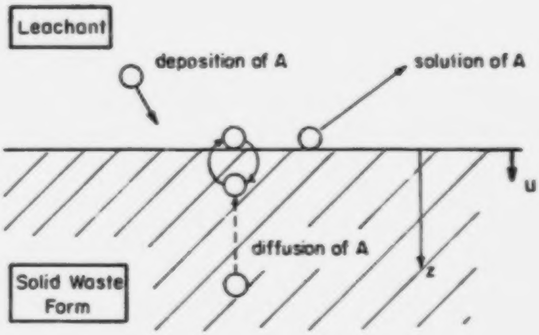

Figure 1. Leach Model

Leaching of species A is assumed to proceed by dissolution of the surface, the rate of which is represented by u, and by diffusion through the following steps:

$$A_{(bulk)} \overset{D}{\rightleftharpoons} A_{(surface\ layer)} \qquad (1)$$

$$A_{(surface\ layer)} \overset{H}{\rightleftharpoons} A_{(surface)} \qquad (2)$$

$$A_{(surface)} \underset{k_d}{\overset{k_\ell}{\rightleftharpoons}} A_{(solution)} \qquad (3)$$

Reaction (1) represents the diffusion of A in the solid waste form in terms of a diffusion coefficient, D. Reaction (2) expresses the equilibrium between the bulk concentration of A in the top surface of the solid and the surface concentration in terms of a solubility coefficient, H. Reaction (3) represents the release of A into the leachant in terms of a rate constant, k_ℓ, and the redeposition of A on the surface in terms of a rate constant, k_d.

Mathematically, if z represents the distance coordinate from the actual surface, one can write:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[D\,\frac{\partial C}{\partial z} + uC\right] \qquad (4)$$

$$C\Big|_{z=0} = Hn \qquad (5)$$

$$\frac{dn}{dt} = -\,k_\ell n + k_d C'_{sol} + D\left[\frac{\partial C}{\partial z}\right]_{z=0} \qquad (6)$$

$$\frac{dC'_{sol}}{dt} = f(\text{leachant flow conditions, solution chemistry,....}) \qquad (7)$$

where C, C'_{sol}, and n represent the concentrations of A in the solid, in the leachant, and on the surface, respectively, while t denotes the time.

The leach rate per unit surface area, L(t), is:

$$L(t) = k_\ell n - k_d C'_{sol} + uC\Big|_{z=0} \qquad (8).$$

With regard to previous modeling attempts, the above formulation is potentially superior because the solid waste form surface and leachant chemistry can be incorporated through k_ℓ and k_d.

The objective is to develop a mathematical formalism yielding the leach rate, L(t), as a function of time for specified leachant flow scenarios and waste form properties. The approach is gradual. Simple scenarios are modeled first; model verification is then attempted on the basis of available experimental data. Successful verification in turn leads to increasing complexity of the scenario to be modeled.

During the quarter, two key technical results were obtained for situations where network dissolution is negligible (i.e., $u=0$) and leachant flow rates are large (i.e., $C'_{sol} = 0$). They are:

1. For simple glasses, the leach rate follows a $t^{-1/2}$-dependence, when interface phenomena are fast, whatever the concentration dependence of the diffusion coefficient might be; the existence of a one-parameter Lie group substantiates the argument mathematically.
2. For a constant diffusion coefficient, analytical solutions have been obtained by using a Laplace transform technique.

Those two conclusions are significant, especially when short-term leaching behaviors are considered. Waste form-leachant interface phenomena can then be predominant, and departures from diffusion-controlled behaviors should be expected.

FUTURE ACTIVITIES

During the coming quarter, verification of the simplified models for which analytical solutions have been obtained will be attempted, with emphasis on waste form-leachant interface phenomena.

SUMMARY

1.2 WASTE PACKAGE

The scope of the Waste Package Task covers waste form investigations and definitions, engineered barrier materials identification, the design and development of waste packages, and the performance assessment of the waste package. The prime objective of this task is to design and develop waste packages that enhance the performance of the total nuclear waste isolation system.

Further studies on spent fuel were made in the areas of waste form assessment, characterization, degradation, and disassembly alternatives impact. Five spent fuel waste forms were analyzed for relative in-repository performance. Their performance was assessed in terms of certain functional requirements in order to evaluate the waste form/stabilizer combinations. Long-term degradation of fuel residing in a repository was studied. The safety, technical, and operating assessments for each of the processes were completed and an economic assessment was made of each alternative process.

Investigations to determine the likely interactions among salt, brine, canister, and waste were continued this quarter. A constant temperature bath system was set up to study the solubility relation in the system $CsCl-NaCl-H_2O$ at 1 atm and between 18 and 120 C. A detailed study of the brines and bitterns present in the Avery Island salt dome was completed.

Candidate barrier element materials are being evaluated by means of corrosion screening tests, using Hanford (basaltic) ground water at 250 C. Corrosion screening of a variety of nickel, iron, copper, titanium, and zirconium base alloys in simulated Hanford ground water was completed.

The spent fuel stabilizer fill process screening test was completed. This test measured the interaction of candidate metal stabilizers with LWR fuel cladding during stabilizer emplacement at elevated temperatures.

Data from a phase diagram showing the generalized relation for the $CaNaPO_4-Ca_2SiO_4$ binary system were used to select compositions for hydration studies. The filtrate analyses on $CaNaPO_4)_{50}Ca_2SiO_4)_{50}$, $CaNaPO_4)_{100}$, $CaNaPO_4)_{20}Ca_2SiO_4)_{80}$, and $Ca_2SiO_4)_{100}$ were completed.

The effects of compaction pressure and material composition upon the compaction density of candidate backfill materials have been examined. As expected, the density of sodium-bentonite compacts increases with increasing compaction pressure at constant water content. At constant compaction pressure, maximum densities were obtained at 5 to 8 weight percent H_2O.

Four permeability cells have been placed in operation, using synthetic Grande Ronde ground water. Pure sodium bentonite has the lowest hydraulic conductivity (7×10^{-13} cm/sec) of the materials tested to date.

Several activities for high-level waste interactions were reported this quarter. Work has started on the time-temperature transformation behavior of TiCode-12 and Ti-50A titanium samples. Possible alternative overpack materials to TiCode-12 have been selected. The first PNL-Sandia joint HLW package interactions test was completed, sampled, and disassembled. Work is continuing on the general corrosion of titanium alloys to establish corrosion mechanisms and screening studies for effective anion getters in brine. Specimens of TiCode-12 were successfully charged with hydrogen from a gaseous environment.

NBS has received the tailored ceramic samples of the magnetoplumbite type from the Energy System Group at Rockwell International, and the preirradiation condition of the samples has been evaluated.

BCL has been assembling an annotated bibliography of documents which will be of use to the waste package design. A draft of the annotated bibliography was submitted to ONWI.

Activities in repository waste package design studies produced a waste package conceptual design for defense high-level waste (Form 1) disposal in salt.

Efforts during this quarter have been directed toward making the needed modifications to the package performance assessment code, BARIER, in preparation for design assessments which will begin next quarter.

Preliminary investigations of the core sample obtained from the Asse mines have begun, and a short summary report on the status of waste-rock testing, in both the laboratory and the field, and on the documentation of the use and need for such tests is being written.

Experimental investigations of synthetic alkali halide single crystals and natural rock salt were conducted this quarter. The objective of these investigations is to study the migration of mixed brine inclusions.

The radar scanning equipment was modified and tested at Avery Island, and the thermal probe measurement in dome salt was completed. Data collection is continuing for stress gage evaluation. A follow-on test plan for a series of three simultaneous heater experiments to detect and measure the associated moisture release under varying field conditions is in the final stage of preparation. The equipment to measure moisture release has been obtained, and detailed planning has begun for the follow-on three-heater experiment.

WBS 1.2.1

PROJECT: Performance Measures Development

PRINCIPAL INVESTIGATOR: Arthur D. Little, Inc. (C. R. Hadlock)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objectives of this program are (1) to provide a complete set of performance measures in six categories (environmental impact, societal impact, safeguards, safety, economics, and resource consumption) for use in analyzing NWTS program options, (2) to provide assistance to ONWI in implementing the measures for NWTS System Evaluation, and (3) to develop a set of performance measures specific to waste package evaluation.

PROGRESS REPORTED PREVIOUSLY

This project began on 21 May, 1980. Principal activities reported previously include these:

- A detailed set of performance measures was developed to categorize each of the six categories listed above. These performance measures represented a quantitative set of characteristics that could be used to measure all relevant aspects of the six categories.
- In order to facilitate the application of the performance measures to a variety of NWTS decisions, logical subdivision charts were developed for each of the six performance categories.
- NWTS criteria documents were reviewed from the point of view of performance measures.
- Decision considerations were identified for the question of whether to build an Intermediate Scale Facility.

The following activities were undertaken during the reporting period:

- Waste package literature was reviewed with a view to determining the availability of specific performance measures that would facilitate decisions concerning the waste package program.
- A program was outlined for the development of performance measures specific to the waste package.

FUTURE ACTIVITIES

The following quarter will involve two principal activities:

- A detailed, comparative chart will be drawn up for a number of NWTS documents relating to waste package criteria and specifications. This chart will be used to provide a preliminary list of potential waste package performance measures.
- Two reference decision points from the NWTS Waste Package Program Plan will be identified for development of specific performance measures later in the project.

In subsequent quarters, performance measures will be developed to characterize the information requirements at the reference decision points.

WBS 1.2.2

PROJECT: Spent Fuel Studies

PRINCIPAL INVESTIGATORS: Hanford Engineering Development Laboratory (HEDL) (R. J. Cash)

ONWI PROJECT MANAGER: J. A. Carr

SPENT FUEL WASTE FORM ASSESSMENT

OBJECTIVE

The objective of this activity is to evaluate each of five candidate spent fuel waste forms for postemplacement performance, with emphasis on their ability to retard the release of radionuclides to the geology. Stabilizer filler material for the waste package is also considered in this assessment.

PROGRESS REPORTED PREVIOUSLY

This is a new activity that started late in FY 80. This task is evaluating the relative in-repository performance of five waste forms, especially their ability to retard the release of radionuclides. The waste forms are under evaluation for prebreach and postbreach performance relative to support against lithostatic pressure, long-term stability for radionuclide retention, minimization of cladding degradation, breach of the canister by possible gas pressurization, heat transfer, and criticality. Performance analysis of each of the waste form-stabilizer combinations for four temperature ranges was also initiated.

ACTIVITIES DURING THE REPORTING PERIOD

Five spent fuel waste forms were analyzed for relative in-repository performance. The ultimate goal of the waste form/stabilizer combination is to prevent radionuclide release for as long a time as possible and then to limit the release rate to a low value. In order to evaluate the waste form-stabilizer combinations, their performance in terms of the following possible functional requirements was assessed:

1. Waste form-stabilizer support against lithostatic pressure
2. Long-term stability for radionuclide retention
3. Minimization of cladding degradation
4. Prevention of canister-repository breach due to pressurization
5. Stabilizer heat transfer
6. The stabilizer as an independent barrier to radionuclide migration
7. Prevention of criticality.

Three stabilizers were considered: inert gas, particulate, and solid. Only generic classes of stabilizers were evaluated, since it was not within the scope of this work to study the merits of individual stabilizer candidates. For some of the functional requirements, a clear-cut division between satisfactory and unsatisfactory performance could not be found. As such, the rankings of many categories could only be interpreted as an attempt at qualification of a particular waste form's ability to meet the possible function. The waste forms were rated overall using a sequential ordering of the functional requirements. Conclusions from the study are as follows:

1. The stabilizer plays a minor role as an independent barrier, unless its corrosion resistance is nearly the same or better than Zircaloy.
2. Criticality can be a concern if a single assembly is placed in a canister with a gas stabilizer, but only if some unlikely event occurs which rearranges the fissile material into an optimum critical shape.
3. Three critical fuel temperatures exist: 425 C, above which the cladding may be compromised; 600 C, where gas release from the fuel may become significant; and 660 C, where significant gas release will occur over the thermal period.

4. As long as the cladding stays intact during the thermal period, the intact waste forms perform equally well in limiting radionuclide migration. If the cladding is compromised during the thermal period, fuel-stabilizer-canister interactions may occur which degrade the fuel significantly. This interaction must be studied if fuel temperatures are set above 425 C, since cladding integrity may be compromised.
5. Waste forms with particulate stabilizers will not appreciably help the canister resist lithostatic pressure.
6. Relative rankings of the waste forms is rather independent of the repository temperature, although the absolute performance may vary with temperature drastically.
7. Ranking of waste forms is fairly independent of the relative weighing of the functional requirements.

Based on these conclusions, the relative performance of the waste forms dictates that the candidates be ordered as follows:

1. The best waste form-stabilizer combination is the intact assembly, with or without end bells, vented or unvented, with a solid stabilizer.
2. A suitable alternative is the combination of bundled close-packed rods with a solid stabilizer around the outside of the bundle to resist lithostatic pressure.
3. The other possible waste forms are of lower ranking, with the worst waste form-stabilizer combination being the intact assembly with a gas stabilizer or the chopped fuel.

FUTURE ACTIVITIES

Comments from ONWI and the other contractors working on the Waste Form Assessment will be incorporated into a final draft report. An evaluation of whole rod testing conducted during 1980 will be completed. New work will include surface area modeling, analyses of the effect of stagnant water in the fuel-cladding gap on the fuel condition, and a comparison of analytic techniques to characterize grain boundaries.

SPENT FUEL CHARACTERIZATION AND DEGRADATION

OBJECTIVE

The spent fuel characterization and degradation study will identify and analyze those characteristics of spent fuel significantly affecting leaching and dissolution and those processes which may be active to degrade such fuel characteristics during the period from emplacement in the repository until breach of the waste package. This work focuses on the performance of the spent fuel waste form and its long-term resistance to the release of radionuclides. Correlations to predict these properties as a function of time will be developed and evaluated based on theoretical considerations and available data.

The work and the correlations developed will ultimately be used to help establish appropriate repository and waste package design limits and in long-term performance assessments of spent fuel package design and candidate repositories.

PROGRESS REPORTED PREVIOUSLY

Spent fuel characterization and degradation studies have identified surface area, surface structure, grain boundary conditions, fission product positions, fuel phases, and valence states as important fuel characteristics which might significantly influence the dissolution and leaching rates of radionuclides. Chemical changes in the fuel, volatile fission product migration, diffusion of gas to grain boundaries, radiation damage due to decay of fission products, and fragmentation due to thermal or mechanical effects were identified as mechanisms which could possibly change spent fuel characteristics during repository residence. HEDL also identified fuel manufacturing and reactor operating conditions affecting the spent fuel characteristics and degradation mechanisms described above.

An analysis of prepressurization gas and fission gas release from spent fuel during geologic disposal was completed. Gas pressurization presents no harmful effects to the waste form, package, or repository. Fuel assembly structural and fracture mechanics analyses of spent fuel under disposal cycle dynamic loading conditions were completed. Results show negligible damage to spent fuel assemblies, because the resulting stresses are low under normal expected transportation and disposal cycle conditions. Fatigue crack propagation analyses demonstrated that large cladding flaws are stable under dynamic response loading conditions. Analysis of pretest destructive examination data for five rods from a Climax Spent Fuel Test assembly was completed.

ACTIVITIES DURING THE REPORTING PERIOD

Long-term degradation of fuel residing in a repository was studied as part of the spent fuel degradation task. It was concluded that in intact fuel volatile fission product migration, fragmentation, and radiation damage would not take place to any extent that could damage the fuel. Gas diffusion would also have little or no effect on the fuel, but it may influence the canister design. Studies using 10-year old fuel indicate that chemical changes should not be a problem either, but it is recommended that the change in valence state with decay of cesium → barium be investigated further.

FUTURE ACTIVITIES

The spent fuel characterization task will be changed to consider and evaluate nondestructive techniques for determining characteristics of spent fuel.

WBS 1.2.2

PROJECT: Spent Fuel Disassembly Alternatives Impact

PRINCIPAL INVESTIGATOR: E. R. Johnson Associates, Inc. (E. R. Johnson)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of this study is to obtain an assessment of the impacts of four spent fuel disassembly alternatives on the nuclear waste isolation system relative to the disposal of unmodified spent fuel. Such impacts will include consideration of relevant technical, operational, safety, and economic factors. The disassembly alternatives will include (1) end bell removal, (2) fission gas venting and resealing, (3) fuel disassembly and close-packing of fuel pins, and (4) fuel chopping and immobilization.

An additional objective, incorporated after work was commenced on the project, is to integrate the results of this study with the results of the evaluation of waste form performance by Westinghouse-HEDL and the development of waste package design criteria by Westinghouse AESD, and to prepare an integrated, stand-alone report.

PROGRESS REPORTED PREVIOUSLY

A review was made of the design of the process and facilities for the packaging and disposal of unmodified spent fuel. This constituted the reference case for analyzing the impacts of spent fuel disassembly alternatives on the nuclear waste isolation system. Preliminary reference PWR and BWR fuel designs were identified.

A review was made of the technology available for accomplishing the prospective disassembly alternatives, and the development of processes for each of these alternatives was commenced. Identification of the additional facilities and materials necessary for accomplishing each disassembly alternative (relative to the base case) was initiated.

Preliminary packaging design parameters were developed for each alternative. Development of a methodology to compare the impacts of each alternative and the effects of human intrusion after repository closure was initiated.

Process flowsheets were completed for the disassembly alternatives, and identification of equipment and facility requirements for accomplishing each of the alternative processes was substantially completed as of 31 December, 1980. Package parameters were established, based on input from Westinghouse AESD, and determination of packaging costs for each of the alternatives was initiated. Radiation exposures for plant workers were in process of development, and a scenario for estimating possible exposures during a well-drilling intrusion into the repository was developed. The procedure for comparative evaluation of the alternative process versus the Reference Process, employing the Figure of Merit (FOM) approach, was further refined, and preliminary conclusions were drawn, pointing to the probable superiority of the alternative of disassembly and disposal of consolidated fuel pins.

ACTIVITIES DURING THE REPORTING PERIOD

Lists of equipment required to perform each of the alternative processes were prepared, and costs were obtained or estimated for this equipment. Facility layouts were completed for each of the alternative processes, as were estimates of the incremental costs of equipment and facilities for the alternative processes.

Modifications to the Bechtel CRRD facilities, necessary to accommodate several minor changes in the Reference Process, were identified, and the impact on the costs of the Reference Process were estimated.

The safety assessments for the alternative processes were completed. Reference and Alternative Processes 1, 2, and 3 (see Objectives) proved to be essentially identical in safety risk, with Alternative 4 showing an enhanced risk from the more drastic processing required by that waste form. The differing impacts of the alternatives on the exposure to members of a drilling crew involved in an intrusion into the repository 100 years after closure were determined; little differentiation among the Reference and Alternative Processes was afforded by this evaluator.

The technical and operating assessments for each of the processes were completed; Alternative Processes 2 and 3 rated slightly lower than the Reference and Alternative Process 1 on both of these assessments, and Alternative 4 rated significantly lower on both.

An economic assessment was made of each alternative process in terms of incremental costs for facilities as compared to the Reference Process, plus estimated operating costs and packaging costs, based on the number of emplacements required for each alternative. The total costs for each alternative over the life of the project were determined and reduced to a unit cost in dollars/kilogram of fuel emplaced. Costs for the Reference Process were modified from the Bechtel CRRD estimate to take into account some minor differences between the process described in that document and the Reference Process used as the basis of comparison. Alternative Processes 1 and 2 were slightly better than the Reference Process, and Alternative Processes 3 and 4 were significantly better.

The four alternative processes were compared to the Reference Process in respect to each of the four assessment areas, employing the Figure of Merit methodology developed during this study. The Figure of Merit developed for each process reflected the results of the assessments made during the course of this study and a comparative analysis of the advantages and disadvantages of each disassembly alternative. Based on this, it was concluded that Alternative 3, involving the disassembly of spent fuel and packaging and disposal of the resulting fuel pins, is the preferred method of disposing of spent fuel.

Work was initiated during this reporting period on the task of preparing an integrated report presenting the significant elements of the results of the studies by E. R. Johnson Associates, Westinghouse-HEDL, and Westinghouse AESD. A proposed outline of the combined report was submitted to ONWI for review and comment, which has been received, and work is under way on the first draft of the combined report.

WBS 1.2.3

PROJECT: Salt-Brine-Waste-Canister Interactions

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, Reston, VA (I-Ming Chou) and Menlo Park, CA (M. A. Clynne)

ONWI PROJECT MANAGER: J. F. Kircher

OBJECTIVES

The objectives are to determine the likely interactions among salt, brine, canisters, and waste at a range of temperatures and pressures which may be considered in disposal of high-level radioactive waste or spent fuel, and to determine the properties of the resultant reaction products at temperatures up to 300 C and pressures up to 2,600 psia.

PROGRESS REPORTED PREVIOUSLY

Data for Brine Migration Modeling

This task began in January, 1980. The Soret coefficient of NaCl is an important factor in modeling the migration rates of fluid inclusions in salt (Anthony and Cline, 1971). However, the experimental data on the Soret coefficient of NaCl are quite limited, and those in mixed electrolyte solutions do not exist. A Soret cell, designed for the direct sampling method, has been assembled and some results obtained for 1 M NaCl solution between 35 and 55 C.

In the brine migration model of Anthony and Cline (1971), the salt concentrations are in molar units, while most of the literature data for salt solubilities are in molal units or in weight percent. Density data for brines are needed to convert the concentration units. Densities of halite-saturated WIPP-A and NBT-6 brines have been calculated from 0 to 100 C using the Potter-Haas (1978) model. These calculated densities are within 1 percent of those measured. In order to further verify or modify the Potter-Haas model, the densities of various binary solutions as well as brines will be measured using a calculating precision density meter. The density meter has been set up and calibrated with 1 to 6 M NaCl solutions.

Solubility of Strontium and Cesium in Complex Brines

This task began in January, 1980. The ^{90}Sr and ^{137}Cs isotopes are the major heat sources in fission products in spent fuel aged more than five years. Brines that might come into contact with a fuel assembly would tend to dissolve strontium and cesium in the assembly as chlorides. Such a fluid contains its own energy source and could migrate and change the thermal evolution of the repository from designed values. In order to better assess the problem, a knowledge of the solubility of strontium and cesium in complex brines is necessary. The solubility relation in the system $SrCl_2$-NaCl-H_2O has been determined from 18 to 115 C, and the solubility of $SrCl_2$ in complex brines has been summarized.

ACTIVITIES DURING THE REPORTING PERIOD

The Soret coefficient of NaCl in 3 M NaCl solution between 40 and 60 C has been determined. The Soret coefficient of NaCl in 6 M NaCl solutions cannot be measured below 40 C due to the precipitation of halite at the cold side of the cell.

A constant temperature bath system has been set up to study the solubility relation in the system CsCl-NaCl-H_2O at 1 atm and between 18 and 120 C. The solubility of halite along four composition lines from NaCl to CsCl-H_2O has been determined between 20 and 95 C. The data obtained have been fitted with equations, and the isothermal solubilities at 25, 50, 75, and 100 C have been calculated. The existence of CsCl-NaCl solid solution has been confirmed by optical and X-ray analyses. A new phase, which is nonisotropic, has been found in the system. The composition and crystal structure of this new phase have not been determined.

Densities for the binary solutions of $MgCl_2$ (0.5 to 3 M) and $CaCl_2$ (0.5 to 5 M) have been measured at 25 C. The concentrations of $MgCl_2$ and $CaCl_2$ solutions were checked by atomic absorption analysis.

To support the Avery Island, Louisiana, heater experiments conducted by the DOE, a detailed study of the brines and bitterns present in the salt dome has been completed. Analytical data include sodium, potassium, magnesium, calcium, strontium, lithium, chlorine, SO_4, bromine, $\delta^{18}O$, and zinc. The bittern brines at Avery Island probably are connate evaporite waters that reacted with sediments and then were incorporated into rising salt domes without major dilution by normal ground water. NaCl brines probably originated either (1) by bittern brines becoming diluted by ground water and then dissolving more NaCl, or (2) above the zinc-bearing strata. Intermediate brines probably were produced by mixing of bitterns with NaCl brines.

Steam condensate samples from the brine migration experiment at Avery Island have been analyzed for deuterium contents. Samples from Test NB (natural brine movement under elevated temperature conditions) have $\delta D \approx 0$ percent standard mean ocean water (SMOW), while those from Test SB (synthetic brine movement under elevated temperature conditions) have δD as high as 47,790 percent SMOW. This result indicates a significant amount of brine had migrated from the brine borehole to the heater borehole within a period of three months. However, the mechanisms for the migration are still not known.

FUTURE ACTIVITIES

This project has been terminated as of this quarter.

REFERENCE

Anthony, T. R., and H. E. Cline, 1971. "Thermal Migration of Liquid Droplets Through Solids", Journal of Applied Physics, Vol. 42, No. 9, pp. 3380 - 3387.

WBS 1.2.3

PROJECT: Desiccant Materials Screening

PRINCIPAL INVESTIGATOR: Lehigh University
(D. R. Simpson)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objectives are to determine the phase relations in the Ca_2SiO_4-$CaNaPO_4$ system and to determine the suitability of selected compositions for backfill by hydration reactions.

PROGRESS REPORTED PREVIOUSLY

A literature review of the binary system Ca_2SiO_4-$CaNaPO_4$ s completed. This revealed major disagreement in the published phase diagrams. With this information, experiments were designed for a systematic study of the phase relation. Preliminary results were presented in the first quarterly progress report and refined in the next. It has been found that $CaNaPO_4$ stabilizes the high-temperature polymorphs of Ca_2SiO_4. The binary system contains a miscibility gap and some low-temperature polymorphic relations. The stabilized high-temperature phases were produced in sufficient quantity to serve as stock material for hydration and sorption studies.

Dynamic and static hydration studies were started with the infiltrating solution containing cesium, strontium, iodine, and rhenium. Some feasibility experiments at temperatures to 300 C were conducted to help establish the identity of the hydration products.

ACTIVITIES DURING THE REPORTING PERIOD

$CaNaPO_4$ - Ca_2SiO_4 Binary

The phase diagram in the last quarterly report showed generalized relations for the $CaNaPO_4$ - Ca_2SiO_4 binary system. These data were used in selecting compositions for hydration studies; however, there was a continuing effort on refining the anhydrous phase relations. A series formed above 1,350 C was held at 942 C for over three months. These compositions confirm the large miscibility gap in the binary system. This experiment will continue for several months, and then the composition of the exsolved phases will be determined to precisely fix the position of the miscibility gap.

The α' field is important because α' is one of the polymorphs of Ca_2SiO_4 which hydrates. Unfortunately, α' formed at high temperatures in pure Ca_2SiO_4 inverts on cooling to γ, a polymorph which does not readily hydrate. Substitution of $CaNaPO_4$ in the Ca_2SiO_4 stabilizes α' sufficiently for preservation at low temperatures, although it is metastable. As part of this study, the minimum quantity of $CaNaPO_4$ required to metastably preserve the α' form was found to be 5 weight percent. With only 4 percent $CaNaPO_4$, the α' Ca_2SiO_4 variant inverts with cooling to the γ form, a process called dusting which has a volume expansion of more than 13 percent.

Hydration Studies

Four compositions were selected for the synthesis of bulk material for hydration studies. These compositions were $CaNaPO_{4)100}$, $CaNaPO_{4)50}Ca_2SiO_{4)50}$, $CaNaPO_{4)20}Ca_2SiO_{4)80}$, and $Ca_2SiO_{4)100}$. Each powder was supported by a fritted glass filter in a glass tube. Water was added to saturation. A daily addition of an aliquot of solution created a head causing a drainage of an equal quantity through the filter bed. The rate of filtration was slow considering the quantities of powders and the aliquot used. The residence time of the filtrate in the filter bed was about seven days. Four different solutions were used with each of the four powders. The solutions contained 0.01 M of NaI, CsCl, $SrCl_2$, and $NaReO_4$, respectively. At this point, the filtrates obtained daily have been analyzed for calcium, sodium, iodine, cesium, chlorine, strontium, rhenium, and pH. The filter beds, now caked, will be analyzed by X-ray fluorescence (XRF).

After 10 to 12 days of the slow filtration, the Ca_2SiO_4 filter bed reacted sufficiently to make the bed impermeable, and the permeability of the $Ca_2SiO_4)_{90}CaNaPO_4)_{10}$ bed was reduced by reaction with some of the solution after 16 days. Neither $CaNaPO_4$ nor $CaNaPO_4)_{50}Ca_2SiO_4)_{50}$ became impermeable by reaction with the solutions.

Over the period of the experiment, $CaNaPO_4$ and $CaNaPO_4)_{10}Ca_2SiO_4)_{90}$ underwent incongruent solution, with sodium being leached from the bed. Interestingly, $CaNaPO_4)_{50}Ca_2SiO_4)_{50}$ did not show the selective leaching of sodium. This may reflect a difference in solubility of the compounds, with the intermediate compound being the least soluble and the least reactive. The leaching of sodium from the bed is desirable because the leached bed is then enriched in calcium and phosphate, which crystallize to the desired compounds apatite. Consistent with this finding is a decreased release of calcium from the bed with increased phosphate in the starting material.

Although the filtrate analyses are complete, the sorptive nature of the bed will be determined by later analyses of the beds with XRF. Based on the solution data, the most effective beds for the removal of strontium are those having some incongruent solution with the release of sodium, namely $CaNaPO_4$ and $CaNaPO_4)_{10}Ca_2SiO_4)_{90}$, suggesting that an insoluble strontium phosphate forms. The solution data indicate that some cesium is sorbed, especially in the beds enriched in Ca_2SiO_4. Some solution contained rhenium, added as $NaReO_4$, as a proxy for technetium. There was extensive sorption or reaction of rhenium with all filter beds. The sorptive capacity was first exceeded for the $CaNaPO_4$ bed.

Some hydrothermal experiments have been completed at 150 and 300 C to aid in the identification of the reaction products and to establish the effect of some of the ions of concern on the nature of the hydration product. Reaction of $CaNaPO_4$ under hydrothermal conditions, with solutions containing Sr, Cs, and I, yielded apatite. This mineral showed a difference in lattice parameters if synthesized in a solution containing Sr or I compared to solutions lacking these ions. The difference is small, but it indicates some substitution of the ions in the crystals and not simply surface sorption. Cesium had no effect and therefore has insignificant substitution in apatite. All of these ions may be surface sorbed; however, the experiments were designed to determine only if there is structural substitution in the crystals.

Hydration of variants of Ca_2SiO_4 at 150 C resulted in the mineral hillebrandite $[Ca_2SiO_3(OH)_2]$. At 100 C for a period of one month, microscopic examination showed extensive hydration, but the product appeared amorphous to X-ray.

WBS 1.2.3

PROJECT: Development of Backfill Materials

PRINCIPAL INVESTIGATOR: Battelle Pacific Northwest Laboratories (E. J. Wheelwright)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVES

The objectives of this project are to define the optimum attributes of backfill materials and to develop the single-component or multicomponent backfill material that most nearly satisfies the prescribed attributes.

PROGRESS REPORTED PREVIOUSLY

The major activities during the last reporting period were: (1) the acquisition of experimental quantities of candidate backfill materials, (2) continuation of radionuclide distribution coefficients with the materials, (3) initiation of compaction tests, and (4) design and construction of the permeability cell systems.

ACTIVITIES DURING THE REPORTING PERIOD

Summary

The effects of compaction pressure and material composition upon the compaction density of candidate backfill materials have been examined. As expected, the density of sodium-bentonite compacts increases with increasing compaction pressure at constant water content. At constant compaction pressure, maximum densities were obtained at 5 to 8 weight percent H_2O.

Four permeability cells have been placed in operation using synthetic Grande Ronde ground water. Pure sodium bentonite has the lowest hydraulic conductivity (7×10^{-13} cm/sec) of the materials tested to date.

Compaction of Candidate Backfill Materials

Clays, quartz sand, zeolites, minerals, metal powders, and graphite are being mixed in various ratios and pressed in an air-hydraulic press to study the relationship of compaction density to material composition and pressing conditions. The objective is to obtain a backfill material composition that will maintain its physical shape during placement and will then retard water intrusion, provide enhanced radionuclide sorptive capacity, provide adequate thermal transport, and buffer the Eh-pH of the backfill environment.

The results of compaction experiments with undiluted sodium bentonite (Volclay CS-50®) are shown in Figures 1 and 2. The solid lines in Figure 1 show the relationship between applied pressure and final density for sodium bentonite containing differing amounts of absorbed water. A reference point of 0.0 weight percent absorbed water was assumed for clay that was heated at 110 C for 16 hours. Vacuum drying at the same temperature for the same time gave comparable dehydration. On this basis, the as-received clay contained 7.5 weight percent absorbed water.

Clays of higher hydration were obtained by equilibration with water vapor in a sealed system. After the pressed pellets were weighed and measured, each was dehydrated by heating in an oven at 110 C for 16 hours. The dehydration results are shown by the dashed lines in Figure 1. The four pellets pressed from previously dehydrated clay powder did not change during the pellet dehydration step.

In Figure 2, pressed pellet density is shown as a function of the water content of the unpressed clay for compacts pressed at four different pressures. The importance of using clay with the proper degree of hydration is clearly shown.

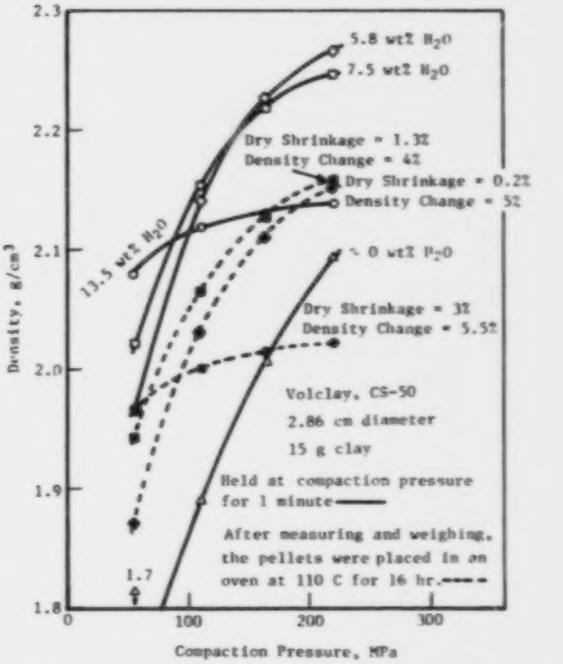

Figure 1. Density of Sodium Bentonite as a Function of Compaction Pressure and Water Content.

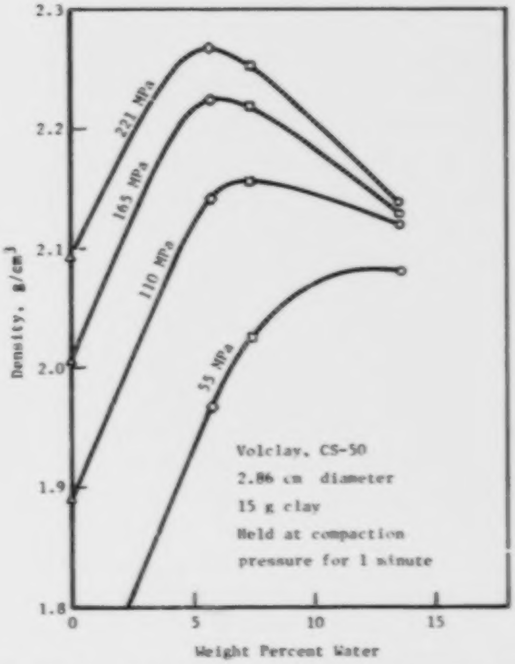

Figure 2. Density as a Function of Compaction Pressure and H_2O Content.

Ground-Water Migration Rates

The primary function of a backfill material is to reduce convective flow of ground water to rates comparable to those of diffusion. This ability to retard convective flow of water is related to the permeability of the backfill. In the laboratory, permeabilities are determined by measuring the parameters in Darcy's law for flow through porous media.

Darcy developed an empirical relation between the volumetric flow rate and the hydraulic gradient across the process medium:

$$Q = \frac{-KA(h_2 - h_1)}{L} ,$$

where Q is the volumetric flow rate, A is the cross-sectional area of the sample, $h_2 - h_1$ is the difference in hydraulic head across the sample length, L, and K is a constant called the hydraulic conductivity (Freeze and Cherry, 1979). The hydraulic conductivity has the units of length per unit time and can be interpreted as the water velocity per unit drop of hydraulic head (Scheidegger, 1960). It is a function of the properties of both the porous medium and the permeating fluid. A parameter k, known as the specific permeability, has been defined to be dependent on only the porous medium. The hydraulic conductivity is related to the specific permeability by the equation

$$K = k\frac{\rho g}{\mu} ,$$

where ρ and μ are the density and viscosity of the permeating fluid and g is the acceleration due to gravity.

Experiments have been initiated to measure the hydraulic conductivities of pure clay and mixtures of clays with quartz sand, natural and synthetic zeolites, metal powders, graphite, and selected

Table 1. Hydraulic Conductivity of Clay-Sand Mixtures.

Percent Sodium Bentonite	Percent Sand, 80-120 mesh	Initial Density, g/cm^3	Hydraulic Conductivity, cm/sec	Time to Migrate 1 Centimeter, yr[b]
25	75	2.1	2×10^{-9} [a]	15
50	50	2.1	3×10^{-12}	11,000
100	0	2.1	7×10^{-13}	45,000

(a) Hydraulic conductivity decreasing with time.

(b) Assuming a hydraulic gradient of 1 cm/cm.

Table 2. Pressure Effects on Hydraulic Conductivity of 50-50 Clay-Sand Mixture.[a]

Hydraulic Gradient	Equivalent Pressure Drop, psi	Time at Pressure, hr	Total Time, hr	Hydraulic Conductivity, cm/sec
1.55×10^5	2200	169[b]	169	4.1×10^{-12}
7.03×10^4	1000	72	241	--
3.52×10^4	500	62	303	3.5×10^{-12}
7.03×10^4	1000	72	375	3.1×10^{-12}
2.11×10^5	3000	97	472	3.1×10^{-12}
1.58×10^5	2250	334	806	2.9×10^{-12}

(a) Sample density = 2.28 g/cm^3.

(b) Includes 64 hours before initial water breakthrough.

minerals as a function of compaction density, material composition, applied hydraulic gradient, and ground-water composition. Later the effects of temperature and gamma radiation will be examined.

Preliminary results from experiments completed and still in progress are shown in Table 1. In these tests, the materials were compacted at 138 MPa. Synthetic Grande Ronde ground water was used as the permeating fluid. As the ratio of clay to sand is increased, the conductivity decreases by several orders of magnitude to less than 10^{-12} cm/sec for pure sodium-bentonite clay. The hydraulic conductivity of the 25 weight percent clay-75 sand mixture shows a decrease by a factor of two over the 189-hour period following the initial breakthrough.

Because of the low permeabilities of these backfill materials, experimental hydraulic gradients must be significantly higher than those expected in a geologic repository in order to obtain data in a reasonable time period. In one experiment, the applied hydraulic gradient was varied in a sequential, stepwise manner, and the hydraulic conductivity was measured at each gradient.

The data given in Table 2 show that for a 50 percent clay-50 percent sand mixture, the hydraulic conductivity is reasonably constant over a hydraulic gradient range 3.5×10^4 to 2.1×10^5. For these gradients the backfill materials appear to follow Darcy's law. Deviations from Darcy's law are not expected until the hydraulic gradient drops below 100. Extrapolations of experimental data to this region will usually overestimate the flow (Mitchell and Younger, 1967). Therefore, the laboratory results are conservative.

Backfill Geochemical Stability

One of the more significant problems of backfill development is providing assurance that the backfill materials will maintain their identities and their desirable properties over the required containment time. A test plan for the hydrothermal testing of proposed backfill materials is nearing completion. The testing program described in the plan is designed to set upper limits on the amount of reaction that is acceptable over the required containment time period and under repository conditions rather than attempting to establish the thermodynamic stabilities. The testing program will consist of both accelerated tests at higher temperatures (up to 400 C) and long-term tests at temperatures representing more reasonable repository conditions.

Because of the difficulties inherent in detecting small quantities of solid reaction products, runs of at least several years' duration will be required at repository temperatures in order to set reasonable upper limits on the amount of reaction that may be expected during the containment period. These low-temperature tests will be carried out with sets of identical samples that can be opened at regular intervals. This will allow early checks for reactions that may adversely affect backfill performance. The autoclave tests will be carried out at pressures of 10 and 30 MPa, representing hydrostatic pressure at a depth of 1,000 m and lithostatic pressure in basalt, the densest repository rock under consideration.

Low-pressure data, to help determine the effects of pressure on backfill material stability, will be provided by tests carried out in Parr bombs under saturated steam pressure. Tests at several pressures are important because many of the proposed backfill materials are hydrous (i.e., clays, zeolites), and their stability may be strongly affected by variations in water pressure.

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WBS 1.2.3

PROJECT: The Chemistry and Physics of Nuclear Waste-Rock Interactions

PRINCIPAL INVESTIGATOR: Pennsylvania State University (W. B. White)

ONWI PROJECT MANAGER: J. B. Moody

NUCLEAR WASTE-ARGILLACEOUS ROCK INTERACTIONS

OBJECTIVE

The objectives are (1) to repeat certain key waste-rock interaction experiments using more reactive younger shales and determine if there is a change in the expected reaction chemistry; (2) to continue the canister-waste-rock interactions and the sequence of experiments on the transport mechanisms of radionuclides in massive shales to determine the distribution of elements along the diffusion gradient and the partitioning of elements among the mineral phases to provide a basis for deducing the transport mechanisms in the actual repository environment; (3) to synthesize the rare earth reaction product phases and determine their X-ray powder diffraction patterns, chemical composition, and the relationship of the various structures as a function of a rare earth ion.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

REPOSITORY BEHAVIOR DEDUCED FROM LITERATURE DATA

OBJECTIVE

The objective is to make a systematic survey of the relevant geologic literature, summarize this information in a way useful for repository design, and draw such conclusions as possible about the repository processes from the experimental data.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

BRINE MIGRATION IN SALT

OBJECTIVE

The objectives are (1) to finalize the characterization of Avery Island salt to determine what new analytical procedures are necessary to differentiate between samples for the migration experiments and (2) to learn more about thermal gradient migration of brine inclusions in polycrystalline salt with the use of the brine migration cell and alternative tracer techniques.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.2.3

PROJECT: High-Level Waste Interactions

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (M. A. Molecke)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objectives are:

1. To quantify the corrosion and metallurgical behavior of candidate HLW canister or overpack materials under environmental conditions to be expected in a salt repository and overtest conditions thereof. To provide and verify predictive models or assessments of the long-term barrier effectiveness of HLW canisters and overpacks based on laboratory, hot-cell, field, and in situ experimental results.
2. To develop and test backfill barriers to retard ground-water intrusion toward the waste package and to significantly delay radionuclide migration (via "getter" additives). This backfill getter is to be compatible for HLW or TRU waste isolation in a salt repository.

PROGRESS REPORTED PREVIOUSLY

Sandia has been experimentally involved in the corrosion behavior of waste container materials since FY 76, and in studies for backfill-getter development since FY 77. Current studies, since July, 1980, have been conducted in a generic manner applicable to the isolation of wastes in a salt repository.

Several candidate canister-overpack alloys were selected after multiple screening tests and assessments for superior corrosion resistance in brines. Several titanium alloys have received additional detailed testing.

To date, no evidence for localized corrosion attack has been found for TiCode-12 sheet or plate samples, or for weldments therein. Also, no stress corrosion cracking was evident in the stress-strain behavior of any TiCode-12 samples tested. There is, however, some evidence of brittle fracture in the fracture surfaces of samples tested at the slowest strain rate used, 10^{-7}/sec.

Initial screening studies on candidate getter materials have been completed. Advanced studies of chemistry and materials testing, geoengineering, and effectiveness modeling are in progress.

ACTIVITIES DURING THE REPORTING PERIOD

Canister-Overpack Development

General Corrosion. Work is continuing on the general corrosion of titanium alloys to establish corrosion mechanisms. The time dependence of the titanium corrosion rate has been studied in tests lasting up to 30 days. The corrosion rate drops rapidly and is essentially negligible after 30 days. The temperature dependence of the corrosion rate has been studied from 25 to 250 C. The pH dependence in boiling HCL has been analyzed in an aggressive corrosion test based on the "knee" of the rate versus pH. Studies of welded samples reveal no degradation due to welding.

TiCode-12 specimens were annealed at 600 C for 72 hours. Raman spectroscopy of the surface oxide layer indicated that the rutile form of TiO_2 had formed.

Surface morphological analyses of TiCode samples held at 250 C in concentrated brine for three weeks showed an enhancement of nickel at the exposed surfaces. This is in agreement with other analyses conducted on similar alloys. It appears that this nickel surface enhancement may be responsible for the corrosion resistance of TiCode-12.

Alternative Materials. Possible alternative overpack materials to TiCode-12 have been selected. These materials are: eight cast irons, Hastelloy C276, Incoloy 825, Inconel 625, Alloy 6X, 2 1/4 cr-1Mo, 9cr-1Mo, 29-4, and 29-4-2. General corrosion screening tests at 150 C in Brine A solution will be carried out.

Process Metallurgy. Work has started on the time-temperature transformation behavior of TiCode-12 and Ti-50A titanium samples. Particular attention is being given to the temperature range near 625 C, where previous study indicates sensitization. The objective of this study is to be able to determine the effects of various microstructures that may develop during welding on the corrosion-stress corrosion susceptibility of candidate titanium canister-overpack alloys.

Hydrogen Embrittlement. Specimens of TiCode-12 were successfully charged with hydrogen from a gaseous environment. The effect of this internal hydrogen on tensile properties (yield strength, ultimate strength, elongation and reduction of area, and fracture behavior) will be measured.

Long-term goals of this task include determination of the maximum tolerable hydrogen level for both loss of mechanical properties and hydride formation, as well as identification of the microstructural location of the hydrogen by using tritium tracer techniques.

Backfill-Getter Development Studies

Screening studies for effective anion getters in brine have continued. A commercially available coconut charcoal was found to have the largest sorption coefficient values, Kd, for TcO_4^- and I^- in brine (Kd = 1,000 ml/g for TcO_4 and Kd = 53 ml/g for I^-). Results of batch sorption measurements have also shown a rank-order correlation between Kd values for TcO_4^- and I^- and the surface areas the charcoal sorbs as measured by the BET method using nitrogen. This correlation supports a surface mechanism for the sorption of these species and suggests that surface area measurements can be useful in screening charcoals.

Measurements of radio-tracer concentration profiles migrating by diffusion in beds of brine-saturated backfill materials are under way. A preliminary assessment of the raw data supports the use of ion exchange as an appropriate model for retardation of Cs^+ and Sr^{++} diffusion in backfill mixtures.

An analysis was completed of the one-week Wyoming bentonite Brine B autoclave experiment carried out at 250 C. A tendency was observed for conditions to develop that favored the stability of the bentonite, but not that of the accessory zeolite (clinoptilolite) present in the system. By virtue of the acid condition that developed due to the heating of a magnesium-rich brine, the accessory calcite originally present in the system was also destroyed, accounting for the profuse evaluation of bubbles noted in the liquid samples taken during the test. Fluctuations in the composition of fluid samples taken during the test were found to be compatible with observed variations in mineralogy.

Other Activities

The first PNL-Sandia joint HLW package interactions test was completed, sampled, and disassembled. This test ran from 25 October, 1980, through 26 January, 1981, at a temperature of 250 C (in a 10-gallon autoclave). This test consisted of HLW glass (76-68 glass loaded with inactive fission products and depleted uranium), a stainless steel 304L waste container, a TiCode-12 overpack, and a bentonite and sand backfill, all contained within a machined rock salt cylinder from southeastern New Mexico. Components of the waste package were severely compromised and in contact with excess concentrated brine to force interactions to occur. This interactions test must be considered a gross overtest of the entire waste package; it was conducted under environmental conditions that are not credible in an actual repository. Empirical test results will be compared with accelerated test results of simpler systems to help elucidate interaction mechanisms and kinetics.

Post-test samples of backfill materials, rock salt, TiCode-12 overpack, autoclave liner (Inconel 600), and test thermocouples (Inconel 600 cladding) were received at Sandia for detailed analyses. TiCode-12 material evaluation was initiated. For baseline property characterization the TiCode-12 was heat-treated, and sample preparation for optical microscopy, transmission electron microscopy, corrosion, hydrogen profiling, Auger analysis, and tensile testing is under way. The tested TiCode-12 overpack was photographed, cut into three equal sections, cleaned in high-purity water, and rephotographed.

Samples of post-test backfill clay were distributed for various types of analyses. Preliminary X-ray diffraction showed that the bentonite retained its integrity during the test and that exchangeable Na^+ (or K^+) was displaced by Mg^{++} (or Ca^{++}). No new clay minerals were formed despite the low pH reported early in the test (1.9 to 3.8). Based on the data available, it seems clear that the basic bentonite structure survived the test, as did the accessory quartz, zeolite, and feldspars in the system. Further work will be required, however, to determine whether a minor mixed layer component developed and whether the clay underwent compositional changes while the basic structure remained intact. Detailed X-ray diffraction and electron microscopic studies are continuing.

FUTURE ACTIVITIES

The following studies initiated this quarter will be continuing with an expanded effort:

1. Complete selection of candidate backfill materials for early field tests.
2. Define HLW backfill and canister field tests.

WBS 1.2.3

PROJECT: Container Barrier Development

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (R. E. Westerman)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objective of this project is to develop materials for the structural engineered barrier components of high-level nuclear waste packages. Structural barriers include the canister, the overpack, and the hole sleeve. The barrier elements must contribute substantially to a barrier system that will hold radioisotope release rates to near-zero values for time periods of ~1000 years.

PROGRESS REPORTED PREVIOUSLY

This project has been under way at PNL in essentially the same form, and with the same basic objectives, since January, 1979. It is now sponsored by ONWI. Until the current fiscal year, however, it was funded by the Division of Waste Products and was reported on as part of the High-Level Waste Immobilization Program.

ACTIVITIES DURING THE REPORTING PERIOD

Introduction

Candidate barrier element materials are being evaluated by means of corrosion screening tests, using Hanford ground water at 250 C. The most promising candidates will be subjected to in-depth enviromechanical testing.

A dynamic autoclave facility is being constructed to expose specimens simultaneously to gamma radiation and high-temperature corrosive environments. A slow-strain-rate test facility has become operational. Initial tests, of Grade 12 titanium sheet stock strained to failure in simulated basalt ground water at 250 C, suggest embrittlement of the material in one metallurgical orientation, i.e., when the material is stressed in the rolling direction.

Screening Tests

Corrosion screening of a variety of nickel, iron, copper, titanium, and zirconium base alloys in simulated Hanford (basaltic) ground water at 250 C was completed. Specimens were exposed in a U-bend configuration, and each specimen contained a simulated weldment. The final three-month, high-oxygen-fugacity portion of a nine-month test was completed, and weight change data were obtained. Corrosion deposits and any depositional scale were removed. As expected, most metals were more susceptible to corrosion with the addition of dissolved oxygen (5 to 7 ppm). The amount of metal weight loss increased about tenfold for most metals. Both Nickel-200 and Zircaloy-2 displayed greater resistance to corrosion in the high-oxygen environment. The ranking of the metals in susceptibility to corrosion remained the same as for the low-oxygen tests. The stainless steels, Inconels, Hastelloy-C, and titanium alloys displayed the lowest corrosion rates; nickel and copper-nickel alloys were intermediate; and the cast irons showed the greatest weight loss. Although cast irons corrode at the highest rate, they still appear to be excellent candidates for structural barrier components in low ion-strength waters. Additional specimens representing thick (5-in.) sections of two cast steels and one ductile cast iron are currently being prepared for additional screening studies in ground waters typical of basalt and tuff formations. Emphasis will be placed on determining the time-dependence of the corrosion rate.

Radiation-Corrosion Facility

In order to predict with any degree of certainty what the corrosion rates of barrier materials will be under actual geologic repository conditions, it is essential that the effects of temperature, pressure, environmental chemistry, and radiation be brought to bear simultaneously on the candidate barrier material(s), which would be maintained in some appropriate flawed and stressed state.

To date, an autoclave test apparatus in a radiation facility has not been available for the program. To remedy this situation, construction of such a facility is currently under way. The radiation will be provided by ^{60}Co sources in an existing HEDL radiation facility. Provision is being made for electrical resistance heating of the autoclaves; dynamic flow conditions; complete chemical characterization of influent and effluent liquids; and electrochemical monitoring of the specimens and the environment within the reaction vessels.

Slow-Strain-Rate Apparatus

A slow-strain-rate test facility is now in use. This facility will ultimately have three pressure vessels and three constant-elongation-rate loading mechanisms. Rupture of metallic specimens under slow-strain-rate conditions in repository-relevant environments, with subsequent fractography and stress-strain analysis, is expected to further define susceptibility of candidate barrier materials to environmentally induced degradation.

Slow-strain-rate tests of Grade 12 titanium have been conducted in flowing simulated Hanford basalt ground water at 250 C. Tests of the LT orientation (specimen stressed in the rolling direction) have been done at 10^{-4}, 10^{-5}, and 10^{-6} in./sec. Preliminary results indicate that ductility, as determined by reduction of area and elongation to fracture, decreased significantly at lower strain rates. This finding indicates that environmental degradation may exist, and that the operative mechanism requires material deformation and exposure to the environment. Preliminary studies (two tests only) of the material in the TL orientation (specimen stressed perpendicular to the rolling direction) gave no indication of similar behavior.

WBS 1.2.3

PROJECT: Stabilizer Materials Program

PRINCIPAL INVESTIGATOR: Hanford Engineering Development Laboratory (R. J. Cash)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objective is to identify, test, select, and qualify stabilizer materials for use in designing spent fuel waste packages. Emphasis is placed on selecting stabilizer materials that exhibit minimal interactions with the other waste package components.

PROGRESS REPORTED PREVIOUSLY

The spent fuel stabilizer temperature limit test was conducted in November. This test was performed to establish a conservative temperature limit for spent light water reactor (LWR) fuel during the stabilizer emplacement process. The diametral strain exhibited by pressurized LWR cladding specimens during a simulated heat cycle for stabilizer emplacement was measured as a function of temperature between 500 and 650 C. Maximum cladding strain criteria can be developed on the basis of restricted stabilizer flow, failure strain, cladding interference with grid spacers, or other possible bases. Application of these potential criteria can lead to stabilizer emplacement process temperature limits of between 590 and 660 C.

Concrete formed under elevated temperature and pressure (FUETAP) was added to the list of potential stabilizer materials. Preparations for the stabilizer prebreach fill process and disposal condition material interaction tests were initiated.

ACTIVITIES DURING THE REPORTING PERIOD

The spent fuel stabilizer fill process screening test was completed. This test measured the interaction of candidate metal stabilizers with LWR fuel cladding during stabilizer emplacement at elevated temperatures. While the test focused on screening of stabilizer materials, interaction information with a candidate canister material (1018 carbon steel) was also generated and will be useful in future considerations.

The material interaction test unit used for the fill process test consisted of a cladding specimen positioned in the center of a 1018 carbon steel capsule. The cladding specimens were fabricated with either Zircaloy-4 or 304 stainless steel with welded end caps. The Zircaloy-4 specimens were pressurized with helium to 650 psi at room temperature; the 304 stainless steel specimens were filled with helium at one atmosphere. These pressures correspond to specimen cladding stresses equivalent to calculated end-of-life stresses in actual fuel rod cladding. Cladding specimens (14 Zircaloy-4 and 14 304) were placed in 28 carbon steel capsules. Individual melts of four zinc and three lead alloys were poured into the capsules containing the two types of cladding specimens (two capsules per cladding type per alloy). This was done in air. The ladle used was cleaned by sandblasting between each alloy melt to prevent contamination of the subsequent alloy. All 28 test units were then placed into an air furnace at 425 C (above the melting point for all alloys) and held for one-half hour. The furnace was allowed to cool over a 30 minute period to 300 C, where it remained for another 15 hours. At this point, the test units were taken from the furnace and allowed to cool in air.

This thermal history simulated a time-temperature cycle which potentially could be experienced by fuel rods in contact with a molten stabilizer in an actual waste canister during the fill process. One half (14) of the test units were subsequently used for the prebreach disposal condition test and the other half for electron microprobe examination to characterize fill process interactions. Neutron radiographs were taken of each fill process test unit from the side and top to help characterize any shrinkage voids that might have occurred during the process.

Metallographic samples were cut from each of the 14 fill process test units and examined using an electron microprobe; photographs were taken of each capsule and cladding-stabilizer interface at 700 to 1000x. Measurable penetration by the metallic stabilizers was observed in the 1018 carbon steel only. The stabilizer interaction ranged from minimal for zinc alloy AG40A to as much as about 0.001-inch penetration with the zinc-copper-titanium alloy, the calcium lead, and the AC41A zinc alloy. The initial surface condition of the capsule components limited interaction determinations to an accuracy of about ± 0.0001 inch.

Table 1 summarizes the interactions observed in the fill process test units. The zinc alloy AG40A stabilizer was the only metal that displayed negligible interaction with the carbon steel. As indicated in the table, none of the stabilizers exhibited interactions with the two cladding materials. Neutron radiography results on each fill process test unit indicated relatively large (approximately 1/8-inch diameter) voids in the commercially pure lead and the calcium lead, smaller voids (less than 1/8-inch diameter) in the zinc alloys, and no voids in the commercially pure zinc and 1 percent antimonial lead.

Stabilizer disposal condition material interaction screening tests were initiated during the quarter. The test units are identical to the units used for the fill process tests. A top end cap was welded onto the unit and a helium cover gas placed inside the capsule to simulate prebreach conditions. The three lead and four zinc alloys are being tested at 300 C, along with four particulate-bentonite combinations. Seven particulates are being tested at a temperature of 500 C. Each of the 18 stabilizer candidates is being tested under prebreach disposal conditions (elevated temperature in the absence of ground water) in conjunction with a Zircaloy-4 and a 304 stainless steel cladding specimen (36 test units). The tests were initiated in February and will be terminated in mid-May. This 3-month test will be used to investigate potential stabilizer interactions with the cladding and capsule materials.

FUTURE ACTIVITIES

The stabilizer prebreach disposal condition tests initiated in February will continue until completion in mid-May. Electrochemical screening tests on metal stabilizers will be initiated.

TABLE 1. Summary of Interactions Observed in Fill Process Tests

Test Unit Ident.	Stabilizer	Carbon Steel Capsule[a] (1018 Penetration)	Cladding Penetration	
			(304 SS)	(Zr-4)
C18	Commercial lead	0.0002 inch	None	
C33	Commercial lead			None
C16	1% Antimonial lead		None	
C30	1% Antimonial lead	0.0002 inch		None
C21	Calcium lead	0.001 inch	None	
C34	Calcium lead			None
C23	Zinc alloy AG40A		None	
C37	Zinc alloy AG40A	Minimal		None
C26	Commercial zinc	0.0003 inch	None	
C40	Commercial zinc			None
C29	Zn-Cu-Ti alloy		None	
C43	Zn-Cu-Ti alloy	0.0008 inch		None
C24	Zinc alloy AC41A	0.001 inch	None	
C38	Zinc alloy AC41A			None

(a) An initial iron oxide layer (∿ 0.005 inch thick) was not evident after the fill process. The penetrations indicated were intrusions into the 1018 carbon steel base metal.

WBS 1.2.3

PROJECT: NBS Independent Measurement Standards Laboratory

PRINCIPAL INVESTIGATOR: National Bureau of Standards (H. T. Yolken and W. P. Reed)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The National Bureau of Standards will (1) promote, on a national and international scale, consistency and accuracy of data used in nuclear waste management; and (2) provide reference data, standard reference materials, research materials, and test methods as required. NBS may also support the DOE isolation program in areas outside DOE's Materials Characterization Organization and will, in accordance with established NBS policy, referee material property data and measurement procedures.

PROGRESS REPORTED PREVIOUSLY

Previous work has been devoted to establishing the program and developing scientific goals. Significant effort has been devoted to completing the literature surveys and developing scientific contacts within the nuclear waste management field. For this particular year, the work has focused on understanding current scientific problems in the field of nuclear waste management.

ACTIVITIES DURING THE REPORTING PERIOD

Waste Forms Leachability Mechanisms

This task is designed to review existing efforts by others and to carry out NBS work in selected areas to improve the understanding of leaching. In addition, the effects of radiation, mechanical properties, microstructure, microchemistry, transport mechanisms, and other disruptive processes will be investigated, and support will be provided to the NBS effort on leachability of waste forms.

Radiation Effects. Tailored ceramic samples of the magnetoplumbite type were received from the Energy System Group, Rockwell International. The preirradiation condition of the samples has been evaluated, and one of the samples is now being irradiated by thermal neutrons to transmute the doped lithium to α particles and tritium to simulate α particle damage in the actual waste forms.

The postirradiation condition of the samples will then be evaluated by using X-ray and neutron methods. An attempt will be made to correlate this study with the leaching rate experiment to be conducted by the Rockwell Group on the irradiated sample.

Phase Stability. This work focuses on the structural integrity of ceramic waste forms. Experimental studies have established that single-phase hollandite specimens can be made from about 1:1:5 to 1:1:4.5 in the system $BaO:Al_2O_3:TiO_2$. No phase appears in the expected hollandite composition range in the system $Cs_2O:Al_2O_3:TiO_2$. Solid solutions of tetragonal hollandite have been shown to extend into the quaternary system $BaO:Cs_2O:Al_2O_3:TiO_2$ to between 10 to 25 percent cesium substituted for barium. In addition, the crystal chemistry of other phases which may be encountered was studied in the systems $BaO:Al_2O_3:TiO_2$, $BaO:MgO:TiO_2$, and $Cs_2O:Al_2O_3:TiO_2$.

Mass Transport. In order to establish the mass transport mechanism in high-level defense and commercial nuclear waste forms, collection of impedance spectra of various hollandite-type ceramics has been started.

Experimental work measuring and evaluating impedance spectra of hollandite-type ceramics, using slightly different stoichiometry and sintered under different conditions, is under way.

Samples having different densities have been produced, and impedance spectra have been measured.

Mass Transport Theoretical Studies. A literature search and study of papers on the leaching of ions from glass and ceramic matrices have been completed. The qualitative characteristics required of any realistic model of the process have been ascertained. Specification of the chemical and physical environment has been shown to be very important, as leach rates are influenced by a large number of factors. Also, the development of diffusion chemical reaction models using MCC-1 as the basis for model specifications has begun.

Mechanical Properties. Since leachability depends on the surface area of the waste form that is exposed to the leachant, resistance of the waste form to fracture and microcracking is a potentially important property.

During this quarter, crack growth data were obtained on two simulated nuclear waste glasses, an NBS-formulated waste glass of composition K-1620, and a glass composition obtained from Penberthy. Crack velocities from 10^{-11} to 10^{-4} m/sec were obtained as a function of stress intensity, K_I, for both compositions in air and H_2O. Extensive scatter in the velocity - K_I data for the Penberthy glass has been attributed to inhomogeneities in the glass composition.

Waste Form Reference Measurement Methods, Reference Materials and Data

Development of Standardized Leach Tests In Cooperation with the MCC. Tests have begun to evaluate the stability of the leachate solutions for elemental analytical measurement. These tests will determine which elements are absorbed on the container walls. In addition, determination of the variance associated with the control of several significant test parameters of the MCC-1 procedure has begun using the NBS glass formulation K-1620. Using this information, the uncertainties in each parameter will then be compared and evaluated for their influence on the results for the MCC-1 test. The improved homogeneity of K-1620 glass should itself aid in evaluating the influence of possible sample heterogeneity on test results.

Research Materials for Leach Tests. Discussion with the MCC and other interested parties resulted in NBS glass K-1620 being selected as one leachability research material. This glass is based on PNL 7668, but without iron, nickel, and chromium. This composition is a transparent glass which greatly facilitates homogeneity determinations. The leach characteristics, determined by courtesy of Battelle Pacific Northwest Laboratory using the MCC-1 test, were found to be satisfactory and not greatly different from PNL 7668. Characterization of the K-1620 glass was carried out to determine those properties that will be required in preparing purchase specifications. This characterization process also indicates there is no phase separation in the glass.

Development of the second research material, much more durable than K-1620, was started. For preliminary testing of these glasses, durability is being judged by weight loss. The results show that some of the experimental glasses have an improvement in durability over K-1620. When promising glasses have been identified, a more complete durability testing will be conducted.

Phase Equilibria Data for Nuclear Waste Form Materials. To aid in the development and understanding of waste forms, particularly ceramics, an evaluated compilation of available phase equilibrium information of particular interest to the nuclear waste field is being assembled. A bibliographic search of Chemical Abstracts, Engineering Index, and the DOE index from about 1970 to 1981 revealed a total of 141 entries, of which only 10 or 11 might be of some interest for phase equilibria data applicable to nuclear waste management. It appears that the most productive approach to expand the available equilibria data on crystalline materials would be through appropriate research.

Container, Overpacks, Sleeves, and Backfill

Container Corrosion. Equipment used in understanding corrosion mechanisms has been obtained and set up. This includes a spectrophotometer for characterizing localized environments and a microprocessor-run electrochemical measurement system to carry out various electrochemical studies. A new cell was designed to study the electrochemistry of alloys surrounding crevices. Also, analytical work has been started on a simulated ground water for use in these studies, based on the standard formulation for ground water developed by Rockwell Hanford.

In addition, a good start has been made on developing a publishable bibliography on the corrosion of canister materials in underground environments.

Backfill. Literature searches have been expanded, and the following areas are being investigated: (1) soil sciences, especially for hydraulic conductivity information; (2) highway and airfield engineering for swelling potentials and test methods used; and (3) the cable industry for information on soil thermal properties.

FUTURE ACTIVITIES

Future activities in each of the areas of work include a number of individual efforts. Some of the highlighted efforts to be undertaken include:

1. Use Small Angle Neutron Scattering (when the facility is complete), as well as other techniques to evaluate alpha damage in waste forms.
2. Determine the exact amount of Cs_2O solid solution in selected hollandite compositions.
3. Further develop mass transport models and equations for the conditions pertinent to MCC-1.
4. Measure crack growth characteristics in a Savannah River Laboratory waste glass and in SYNROC B from Lawrence Livermore Laboratory.
5. Complete the development of specifications, including a list of possible suppliers, for the first waste glass research material, and study an alternative definitive multielement analytical technique for leachate solutions.
6. Study the localized environment in pits and cracks in order to understand corrosion mechanisms of container material; work on a corrosion bibliography.
7. Hold the backfill workshop, and develop a consensus position on the function properties and measurements of backfill as a guide to future NBS backfill activities.

WBS 1.2.4

PROJECT: Repository Waste Package Design Studies

PRINCIPAL INVESTIGATOR: Westinghouse Electric Corp. (D. Newby)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of the program is to develop the preliminary designs for practical, easy-to-handle waste packages that will retain nuclear wastes for long periods of time and then effectively retard their release so that the natural barriers provided by the geology can reduce their transport to the point where they pose no threat to man and his environment.

PROGRESS REPORTED PREVIOUSLY

The contract was initiated in May, 1980. Efforts in preceding quarters have been directed toward obtaining a foundation in waste package design technology, preparing the program's quality assurance plan, developing an engineered waste package system specification document, initiating waste package conceptual design efforts, and establishing and participating in interface coordination efforts with other ONWI/NWTS contractors.

Waste package design activities included the issue of a final draft of the Waste Package Design Specification to become the guide for all waste package designs.

ACTIVITIES DURING THE REPORTING PERIOD

A draft report entitled Engineered Waste Package Conceptual Design: Defense High Level Waste (Form I) Disposal in Salt was submitted to ONWI. The report discusses waste package conceptual design studies for Form Number I of Defense High-Level Waste (Savannah River) in a salt geological formation.

The introduction to the report states that the primary objectives of the engineered waste package have been categorized into two time periods: (1) Thermal Period (up to 1000 years after emplacement), and (2) Post-Thermal Period. The Introduction goes on to say that "The engineered barrier system which includes the waste form is designed to perform the function of retardation of radionuclide release rate during both periods. This report is primarily concerned with the retention of radionuclides during the first 1000 years (Thermal Period), since the waste form development activities are outside the scope of this study.

"The package must be designed to provide the option for retrievability during the early years after initial repository operation. This will allow the removal of the packages as a viable option in the event of unforeseen circumstances.

"The designs presented in this report are conceptual and do not have complete analytical support. There are also many features and material considerations which must be the subject of future test programs."

One section of the report identifies areas where questions remain to be answered.

WBS 1.2.4

PROJECT: Design Specification Support

PRINCIPAL INVESTIGATOR: Battelle Columbus Laboratories (N. E. Miller)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of this program is to support the development of waste package criteria responses, conformance, and predesign specification studies.

PROGRESS REPORTED PREVIOUSLY

This study was begun in April, 1980. Efforts were initiated on four tasks with the following objectives:

1. To review and interpret the ONWI criteria documents and to develop waste package design responses to each criterion.
2. To assemble an annotated bibliography of documents which will be of use to the waste package designer.
3. To develop a dictionary of waste package-related terms for use by the ONWI waste package development staff and contractors.
4. To develop broad guidelines for the waste package design describing aspects of waste management systems that interface with the waste package.

ACTIVITIES DURING THE REPORTING PERIOD

The first and third tasks were discontinued. The second was continued as originally planned, and the fourth was reduced to preparing a summary of the information accumulated so far.

During this reporting period, the draft of the annotated bibliography was submitted to ONWI. During this effort, over 1,200 references were identified by manual and computerized searches. Approximately 1,000 of these citations were reviewed, and about 950 were abstracted for the report.

FUTURE ACTIVITIES

Minor revisions will be made in the draft of the annotated bibliography, and the final document will be completed during the third quarter. A summary of the work on the fourth task will be submitted to ONWI in FY 81.

A new task will begin in April, 1981. Its objective is to evaluate two waste package conceptual design reports for compliance with the ONWI criteria documents. The final report of this evaluation is planned to be submitted to ONWI in FY 81.

Also, technical assistance will be provided to the ONWI staff in the preparation of draft documents for Waste Form Specifications and Waste Package Specifications. These draft reports are planned to be completed in FY 81.

WBS 1.2.5

PROJECT: Waste Package Performance Evaluation

PRINCIPAL INVESTIGATOR: Science Applications, Inc. (D. H. Lester)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

Under previous projects, various engineered barrier concepts for geologic isolation have been analyzed to model waste package degradation and nuclide release. The objective of this study is to modify these existing waste performance models for particular radioactive waste and package designs and to evaluate the packages' lifetimes and radionuclide release rates and concentrations at the package-repository boundary as functions of time.

This project interfaces with Repository Waste Package Design Studies, WBS 1.2.4, to develop conceptual, and later detailed, designs for waste packages. The two projects are initial efforts to develop and qualify waste packages for the waste isolation system.

PROGRESS REPORTED PREVIOUSLY

This project was started on 23 February, 1981. This is the first quarterly report.

ACTIVITIES DURING THE REPORTING PERIOD

The package performance assessment code BARIER was developed in a previous project and is described in Lester et al (1980). A baseline version has been established as the starting point for further revisions to accommodate evaluations of package designs. Efforts during this quarter have been directed toward making needed modifications to the code in preparation for design assessments which will begin next quarter.

Four types of modifications are in progress:

- Housekeeping Changes to improve convenience and efficiency. These include items such as improved output file handling and ability to check terminal input data prior to execution.
- Data Base Revision to accomodate materials not previously considered and geometry changes, site description changes (consistent with reference repository conditions), and other code revisions.
- Correction of Errors
- Conceptual Model Revision.

Two errors have been found in the baseline code. The first was discovered immediately after the completion of the FY 80 project. A stress yield criteria equation had an incorrect grouping under a square root resulting in erroneous failure times. This was corrected last year, and errata were issued to ONWI. The second error involves an index called NTERM in the RELEAS subroutine which was set to 99 rather than 30. This causes no problem on the SAI computer (DEC-10) but could on other systems.

Three conceptual model revisions are in progress. These are being done to make the evaluations more realistic. The first of these is the consideration of significant hydrostatic pressures described in the reference repository condition. Such high pressures were not previously considered (up to 1,000 psi) except in creeping geologies such as salt. Hydrostatic pressure is being considered separately from lithostatic creep pressure. The second change involves the separation of bulk and local corrosion effects. Previously the collapse of a wall was attributed to loss of strength by wall thickness reduction due to either bulk or local corrosion. That is, if one pinhole or crack were to propagate a percentage of wall thickness, then the entire wall was considered reduced in thickness. In the revised model local corrosion will be allowed to cause leaks, but only bulk corrosion will cause loss of effective structural thickness. This will require consideration of hydrostatic pressure and corrosion on inner barriers if outer barriers are leaking, even though an outer wall has not failed due to lithostatic pressure. Both of the conceptual revisions are depicted in Figure 1. The third revision involves changes to the nuclide release model (RELEAS) to accommodate radiodecay in the backfill holdup and calculation of the declining release portion ("tail") of the release curve. The new subroutine will be solving the basic transport equation,

$$\frac{\partial C}{\partial t} = k \frac{\partial^2 C}{\partial x^2} - bC,$$

where

$$k = \frac{D_e}{(1 + \frac{K_d \rho}{\varepsilon})} \qquad b = \frac{\lambda}{(1 + \frac{K_d \rho}{\varepsilon})}$$

D_e = effective diffusivity

K_d = backfill retardation factor

ρ = backfill bulk density

ε = backfill porosity

λ = decay constant

Flux boundary conditions are applied which account for leaching, resistance of partial barriers, and characterization of the repository environment.

FUTURE ACTIVITIES

The code modifications described in this report will be further developed, incorporated in the code, and checked. During next quarter preliminary runs in the new model will be started, and some sensitivity screening will be done to reduce the total run matrix for evaluating the new design. Performance evaluation will be initiated.

REFERENCE

Lester, D. H., R. T. Stula, B. E. Kirstein, and T. E. Albert, 1980. "Waste Package Performance Analysis", in Proceedings of the 1980 National Waste Terminal Storage Program Information Meeting Columbus, OH, December 9-11), ONWI-212, Battelle Memorial Institute, Columbus, OH, pp. 328-334.

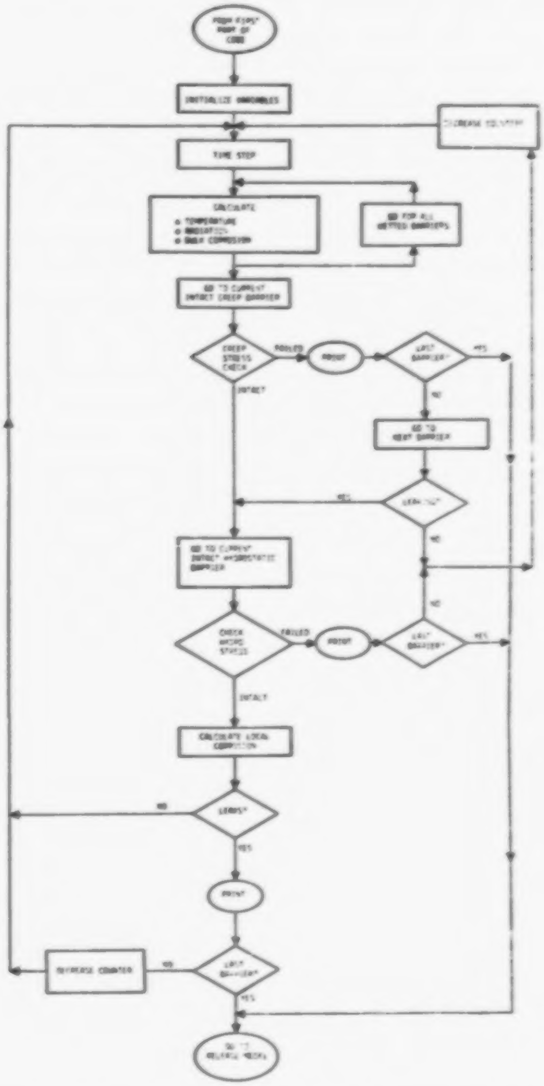
FROM FIRST PART OF CODE
INITIALIZE VARIABLES
DECREASE TIME STEP
TIME STEP
CALCULATE
• TEMPERATURE
• RADIATION
• BULK CORROSION
DO FOR ALL WETTED BARRIERS
GO TO CURRENT INTACT CREEP BARRIER
CREEP STRESS CHECK
FAILED
PRINT
LAST BARRIER?
YES
NO
INTACT
GO TO NEXT BARRIER
LEAKING?
YES
NO
GO TO CURRENT INTACT HYDROSTATIC BARRIER
CHECK HYDRO STRESS
FAILED
PRINT
LAST BARRIER?
YES
NO
INTACT
CALCULATE LOCAL CORROSION
LEAKS?
NO
YES
PRINT
LAST BARRIER?
NO
INCREASE COUNTER
YES
GO TO RELEASE MODEL

Figure 1. Simplified Diagram for Corrosion and Failure Routine.

WBS 1.2.5

PROJECT: High-Level Waste Form Preparation (HLWFP)

PRINCIPAL INVESTIGATOR: Battelle Pacific Northwest Laboratories (D. H. Siemens)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of this program is to characterize, prepare, and ship the NWVP-2 waste log to the EMAD Facility. At EMAD, the waste log will be sealed in a storage canister and then shipped to Hanford, Washington, for storage in the Near-Surface Test Facility (NSTF).

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.2.5

PROJECT: Cooperative Field Tests in Salt

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (T. O. Hunter)

ONWI PROJECT MANAGER: A. J. Coyle

OBJECTIVE

This project supports the collection of field test data necessary for Repository Data Base Development for salt, specifically: (1) to provide management support for field testing activities, (2) to evaluate and improve existing techniques for in situ rock characterization, (3) to perform experiments in southeastern New Mexico that address issues identified in the repository development program, and (4) to support the international cooperative program on nuclear waste management.

PROGRESS REPORTED PREVIOUSLY

The Cooperative Field Tests (CFT) program was instituted to coordinate various support activities provided by Sandia to ONWI in the repository data base development area. Formalization of the program was initiated in September, 1980, and is designed to respond to issues regarding repository design data collection requirements. The CFT is broadly defined within four major categories: management, experimental technique evaluation, test series in southeastern New Mexico (SENM), and support for international programs. This report is the first formal quarterly report prepared in the CFT.

ACTIVITIES DURING THE REPORTING PERIOD

Radar Scanning Equipment

The modified circuitry system was exercised in conjunction with the Trapped Gas Experiment during March. The system operated satisfactorily, even though no gas pockets were penetrated. Plans are in progress to reenter the Avery Island mine for further evaluation of the system.

The following experiments were conducted in situ to obtain data and evaluate experimental techniques and equipment:

Thermal Probe

Thermal conductivity measurements were made in dome salt in the Avery Island mine from mid-September through late November, 1980, using the Sandia-developed thermal probe. A method of analyzing data from line source thermal conductivity probes was developed. Since the method accounts for contact resistance and can use nonlinear, relatively early temperature data, useful data can be obtained from shorter probes and shorter runs. This may permit much more rapid evaluation of possible repository sites.

Reduction and analysis of the data have been completed, and the final report has been started.

Stress Gage Evaluation

Data collection will continue at the Avery Island heater experiment until the experiment is terminated by ONWI.

Radiant Heater Experiment in SENM Mine

The first heater experiment was terminated in November, 1980. Analysis is in progress, and the preliminary results were reported previously. A follow-on test plan for a series of three simultaneous heater experiments for detection and measurement of the associated moisture release under varying in situ conditions is in the final stage of preparation.

Follow-on Three-Heater Experiment for the Mississippi Chemical Mine

The equipment for measuring moisture release has been obtained, and detailed planning has begun for the experiments, which will begin in June, 1981.

Waste Packaging Materials Testing in SENM Salt

The rough draft of the test plan for an experiment in SENM is nearly complete. This effort will be directed toward obtaining performance data on backfill material, and overpack alloys will be obtained. Arrangements for the instrumentation, recording, and siting of this set of experiments have been initiated.

Trapped Gas Experiment (TGE) Status

This experiment was conducted in mid-March, 1981. Radar-scanning activities and drill-rig operations were performed at three possible gas-producing sites in the mine. The in-mine work on the TGE was temporarily suspended, pending assessment of information gathered to date. Generally the initial setup and operation of the system worked satisfactorily, but some modifications to the techniques are required. No gas pockets were intercepted at the three sites selected for drilling. Those sites were selected on the basis of a radar-scan comparison to an earlier unmeasured gas pocket penetration. This earlier pocket vented for approximately 1.5 hours from a depth of 12 feet in a suspected clay seam. The three selected sites were located at distances of about 240, 320, and 430 feet from this hole and showed similar radar profiles.

Modifications to drill collars and radar equipment are being made to eliminate problems identified in the current phase. Follow-on experiments will begin in June, 1981, to evaluate radar-scanning capability. (See Christensen, 1981.)

Support for International Programs

Sandia offered to provide strain gages and an overpack to FRG to use in experiments at Asse. No response has been heard from FRG. Hahn-Meitner Institut (FRG) staff were not too interested in performance codes offered by Sandia.

FUTURE ACTIVITIES

The following activities are planned:

1. Develop a test procedure for radar-scanning evaluation at the Avery Island mine, and conduct the evaluation using the improved system.
2. Evaluate alternatives for conducting the TGE in SENM.
3. Conduct follow-on three-heater experiments in SENM mine.
4. Complete the test plan for the waste package experiment in SENM mine.

REFERENCE

Christensen, C. L., 1981. *Test Plan, Trapped Gas Experiment*, Sandia National Laboratories, Albuquerque, NM, February (limited distribution).

WBS 1.2.5

PROJECT: Thermal Gradient Brine Migration

PRINCIPAL INVESTIGATOR: University of California (D. R. Olander)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this investigation is to develop a rigorous model of thermal gradient brine migration in natural rock salt.

PROGRESS REPORTED PREVIOUSLY

This study was started on 1 July, 1979. Progress reported previously has established a number of features of the migration process. For the all-liquid inclusions in synthetic single crystals:

- The rate-controlling step is associated with the kinetics of dissolution at the hot face, rather than a liquid diffusion-controlled process.
- Dislocations provide the necessary imperfections needed to permit dissolution.

In keeping with these features, experiments have been performed to determine the migration velocities of all-liquid inclusions in KCl and NaCl single crystals in a temperature gradient. The velocity was found to vary as the temperature gradient raised to power > 2. This is at variance with a liquid diffusion-controlled process, or one with linear interface kinetics, both of which predict $V_{incl} \alpha \nabla T$. Hence, the Anthony-Cline and Geguzin-Dzyuba-Korzhanov theories appear to be inadequate to describe the migration process and have been suitably modified. The present results can be successfully explained by the Burton-Cabrera-Frank theory of crystal growth, as applied to dissolution.

The project was inactive during the first quarter of FY 81. Work on natural rock salt was started on 15 January, 1981, and this constitutes the first quarterly progress report on that effort.

ACTIVITIES DURING THE REPORTING PERIOD

Experimental Investigations

Synthetic Alkali Halide Single Crystals. The objectives were as follows:

- Study the migration of mixed brine inclusions of NaCl + $MgCl_2$ or NaCl + $SrCl_2$ in KCl and NaCl single crystals.
- Study the effect of dislocation density in the crystal on the inclusion velocity.
- Continue the work begun previously on the migration of pure brine inclusions in KCl single crystals with variable axial loads.

Some migration experiments were completed on all-liquid inclusions fabricated from 2.1 M $MgCl_2$ solution in NaCl single crystals. For similar axial loads and temperature gradients, the velocity data for mixed-brine inclusion migration are of the same order of magnitude as in the case of pure NaCl inclusions. The dependence of the velocity on the calculated temperature gradient within the liquid is linear, suggesting that linear kinetics may, in fact, be operative. This is in contrast to previously reported results where $V_{incl} \alpha (\nabla T)^2$. The data are being fitted to the velocity equations of the proposed model. Experiments with $MgCl_2$ brines are continuing, and those with $SrCl_2$ brines will begin shortly.

In order to quantify dislocation density effects on migration velocities, the dislocation density will be measured by the Lang topography technique. This work is making slow progress.

Initial results on migration of inclusions in KCl single crystals suggest that the migration velocities increase with increasing axial load. Further experiments are continuing to quantify the relationship and to clarify the mechanisms.

Natural Rock Salt. The objectives were as follows:

- Acquire natural rock salt and fabricate small specimens.
- Design and construct a new experimental setup to follow the migration behavior of NaCl + $^{85}SrCl_2$ mixed brine inclusions by gamma activity counting techniques.
- Follow the migration behavior of NaCl + $SrCl_2$ mixed brine inclusions in the rock salt in the existing visual microscope setup.

Theoretical Investigations

The objective is to refine the preliminary gas-liquid inclusion model by considering a realistic inclusion geometry. For this purpose, numerical models of thermocapillarity-driven flows will be adapted to the brine migration process. An existing numerical analysis of a hemispherical noncondensible gas bubble placed on a flat heated surface has been modified to include mass transfer through the bubble interface.

FUTURE ACTIVITIES

Work along the above lines will be continued. Testing and calibration of the new experimental setup will begin shortly.

Rock salt from Cypress Creek and Richton Dome has recently been acquired, and small specimens will be fabricated and characterized. Experiments with these specimens will begin immediately thereafter.

The numerical analysis of the hemispherical gas bubble on a flat heated surface will be adapted to the brine migration process.

The accuracy of the numerical solution for spherical geometry will be assessed, and the results will be compared to the perturbation method.

SUMMARY

1.3 SITE

The objective of the Site Task is to identify and characterize sites within the contiguous United States that are suitable for construction and operation of a mined geologic repository for the long-term isolation of radioactive waste. Site investigations involve developing siting criteria and identifying and screening media and geosystems using these criteria. Evaluation of these media is being carried out by relating them to the NWTS-33(2) criteria document. These evaluations are currently in various stages of the screening process.

Coring and short-term hydrological testing of the Gibson Dome No. 1 borehole in the Paradox Basin were completed in early January, 1981. Total depth of the hole is 6,384 feet in the Ouray limestone of Late Devonian or Early Mississippian age. Because of budget reductions, long-term hydrological testing of the hole was postponed indefinitely. Writing of the Area Characterization Report on the four Paradox Basin study areas was initiated.

The final Regional Environmental Characterization Report was issued for the Paradox Basin. Draft reports on the recommendation of study areas and environmental area studies were issued for public comment. Bechtel prepared reports on the environmental evaluation of the Utah area studies and on water availability in southern Utah, and work on the transportation access study continued.

The Texas Bureau of Economic Geology completed a topical report on the regional dissolution of Permian salt in the West Texas Panhandle. Stone and Webster Engineering Corporation completed a preliminary draft Subregional Geological Characterization Report that identifies several large areas in the Palo Duro basin suitable for future detailed investigations.

The principal activities in the Gulf Coast Salt Dome Region were the preparation of a number of reports and the continuation of several research projects.

Twelve topical reports, five special reports, and fifteen well completion reports were in various stages of completion during this quarter. These reports are outgrowths of the Area Characterization Reports. They deal with topics of special interest or are summaries of specific data collected.

Research into the Near Dome and Deep Basin Hydrology continues. The timing of the dome growth cycles in the East Texas Basin is being investigated.

Reports detailing the analyses of the Quaternary Geology and the core samples of Rayburn's Dome and the Jefferson Island Mine flooding are proceeding.

The hydrology of the three salt dome basins and individual salt domes continues to be studied by several groups. This work is extremely important in determining the future hydrologic stability of the domes.

The final Regional Environmental Characterization Report and the final Regional Summary Report were issued for the Gulf Coast Salt Dome Region. Work began on the Site Characterization Plan.

The regional literature search in the Minnesota portion of the Lake Superior Region was completed, and a preliminary draft report was prepared.

Approval was received from DOE to initiate regional literature searches in New York, Pennsylvania, Massachusetts, Connecticut, New Hampshire, and Maine (Northeast Region). Pacific Northwest Laboratories (PNL) began gathering baseline data in these states.

Approval was also received from DOE to initiate regional literature searches in all five Southeast Region states: Maryland, Virginia, North Carolina, South Carolina, and Georgia. Oak Ridge National Laboratory (ORNL) has entered environmental data for these states into their computer for analysis and mapping.

Two final reports, Criteria and Methodology for Region Selection and Evaluation of Regional Repository Siting in the National Waste Terminal Storage Program, both dealing with generic siting issues, were completed.

In the project on Effects of Organics in Deep Ground Water, humic and fulvic acids form insoluble complexes with uranium and thorium under acidic conditions. These organic acids, commonly found in deep ground waters, may, under certain physicochemical environments, serve as radionuclide immobilizing agents.

Leach tests conducted by WRIT program have shown that dissolution kinetics is strongly dependent on glass composition as well as pH. Fluid composition also strongly affects leaching rate with bicarbonate solutions and has the strongest effect for all radionuclides except technetium.

Modeling of glass leach test results using a geochemical computer code (EQ3) shows that solutions are at saturation with respect to quartz, but also that other minerals will precipitate out of the fluid on cooling and will strongly affect the fluid chemistry.

Neodymium isotope data for reactor Zone 9 of the Oklo natural reactor were used to reconstruct the operating parameters of this reactor zone. The identification of small amounts of 235-depleted uranium in rocks external to reactor Zone 9, and beyond the range of neutrons produced in reactor Zone 9, indicates that small amounts of uranium were removed from the reactor zone and redeposited meters to tens of meters away from the reactor zone.

It was found that the water in streams draining the Morro do Ferro deposit in Brazil and the surrounding terrain all have high concentrations of total thorium, with the highest concentration found for the stream draining the Th deposit. Filtered samples from the stream draining the deposit have over a 10-fold higher concentration of Th than do the other samples.

In Conasauga shale, the low-temperature (<150 C) mineral suite contains illite, illite-smectite, chlorite, potassium and sodium feldspar, biotite, kaolinite, glauconite, quartz, and minor muscovite. Near the end of the diagenetic stage (250 C), potassium feldspar and kaolinite are destroyed, and most of the illite-smectite is converted to illite and chlorite. Biotite, sodium feldspar, and glauconite do not appear to have been affected during diagenesis. At temperatures of 250 C to 425 C, illite and biotite enter into reaction and phengite (green mica), white mica, and chlorite are formed.

WBS 1.3.1

PROJECT: Site Baseline

PRINCIPAL INVESTIGATOR: Envirosphere (J. Franco)

ONWI PROJECT MANAGERS: N. J. Beskid and D. B. Shipler

OBJECTIVE

The objective of this task is to prepare drafts of geologic and environmental characterization and site selection documents which, when finalized, will form the framework for obtaining and documenting the base data necessary for site identification and characterization to be used in subsequent licensing proceedings.

PROGRESS REPORTED PREVIOUSLY

Work continued on revising the National Site Characterization and Selection Plan (NSCSP) and accompanying Environmental Assessment (EA). The NSCSP was revised in accordance with DOE comments and suggestions.

The two topical reports, the Region Selection Criteria and Methodology Report and Regional Repository Siting Report, were completed in draft form.

ACTIVITIES DURING THE REPORTING PERIOD

The National Site Characterization and Selection Plan/Environmental Assessment underwent further revisions and will be released during the fourth quarter, FY 81. The two topical reports, *Criteria and Methodology for Region Selection* and *Evaluation of Regional Repository Siting in the National Waste Terminal Storage Program*, were revised and completed as final reports.

WBS 1.3.2

PROJECT: Acoustic Studies in Climax Stock

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (E. Majer)

ONWI PROJECT MANAGER: A. Andrews

OBJECTIVE

The experiment seeks to develop and evaluate techniques for monitoring the integrity of nuclear waste repositories and to determine the suitability of granite or hard rock as a repository medium. Microseismic (MS), acoustic emission (AE), and waveform analysis techniques are employed at the Nevada Test Site to study the relationship between discrete rock failure and stress release relative to thermal effects, radiation degradation, mine geometry, and canister spacing.

PROGRESS REPORTED PREVIOUSLY

The experiment began in December, 1979, with the emplacement of AE sensors (piezoelectric crystals), preamplifiers, and a 15-channel transient waveform analyzer. The sensors were deployed in a 15-station, three-dimensional array centered on the canister drift which would eventually house the spent fuel. Preliminary findings after some three months of monitoring prior to waste emplacement and heater turn-on and several months following were:

1. The repository rock has average P- and S-wave velocities of 5.5 and 3.2 km/s, respectively, for a Poisson's ratio of 0.25, values typical for granite.
2. The rock on this scale is not homogeneous in velocity and attenuation properties with seismic waves at frequencies between 1 kHz and 10 kHz. Ongoing observations of these properties may offer a means of mapping the progress of fracture zones or zones of alteration.
3. Discrete seismic events occur within the mine structure that are not associated with the canister area. They seem to occur at a rate of one to three per week as discrete fractures with source dimensions of the order of centimeters, presumably in response to stresses induced by mining, drilling, and coring.
4. There was no evidence that strong ground motion within the repository, associated with nearby underground nuclear explosions, induces cracking or otherwise enhances the microfracturing process.
5. After waste emplacement and heater turn-on, AE/MS activity was detected near canisters 11 through 15. The main effect seemed to be in the concrete floor above the waste canisters, based on the ability to discriminate events in rock from the AE/MS activity in the concrete.
6. Except for one period of high activity in early December, the AE/MS activity decreased to less than one event per week. Velocity and attenuation measurements using active acoustic sources were started to determine changes in rock properties. Attenuation measurements seem much more sensitive than velocity measurements. Relative S-wave to P-wave amplitudes indicate a dewatering of the rock in heated zones.

ACTIVITIES DURING THE REPORTING PERIOD

Acoustic emission and P- and S-wave velocity and amplitude measurements (with active source) continued at the Climax repository simulation. AE activity was seen to decrease to one to two events per month during the first quarter of 1981. Several events were detected within a few days of the canister exchange (14 January) in the vicinity of the new canister. However, no events were detected the week after the exchange.

The Qs/Qp ratio (where Q designates specific attenuation) continued to increase for wave paths through the heated zone. As the heat pulse (60 C 1 to 2 m from canisters, 45 C 3 to 4 m, ambient = 23 C) broadens and travels out in the rock, the thermal expansion may be dewatering the rock. Although no change in velocity has been seen (either P or S), there has been a systematic increase in both P and S amplitudes, with S showing the greatest increase.

During January, an experiment was conducted to determine the amount of ground motion due to a nearby nuclear explosion (equivalent magnitude $M_L = 5.4$). The maximum acceleration at 5 Hz was slightly less than 0.01 gravity. This is very small for being so close to this size of source. Relative to strong ground motion from nearby sources (earthquakes or nuclear explosions), the Climax granite appears to be a very competent material.

A decision was made to progress to the next developmental stage of the in-field data acquisition and analysis system, ASP (Automatic Seismic Processor). An LSI-11 computer will be interfaced with the present ASP. Its responsibility will be to provide more speed and computational power than is presently available with the ASP now being used. The present ASP will still monitor each data channel and detect time, measure amplitudes, and perform fast Fourier transform analysis on the P- and S-waves. These data are then fed to another microcomputer, which determines the validity of the event and either rejects the data or performs further processing. The data will be fed to the LSI-11 system after an event has been determined to be valid and processed with greater speed and sophistication.

FUTURE ACTIVITIES

AE/MS and waveform monitoring will continue at the Climax stock. Development will continue on the ASP system in parallel. As the extensometer and thermal data become available, the emphasis will be placed on correlating these data with the mechanical properties of the rock relative to AE/MS and waveform characteristics.

WBS 1.3.2

PROJECT: Shale Structure Studies

PRINCIPAL INVESTIGATOR: Georgia Institute of Technology (C. E. Weaver)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

One objective is to develop geothermometry methods to determine the maximum temperature to which shales have been subjected during their burial history to determine the past thermal history of shales and evaluate which would be best suited for a HLW repository site. Another objective is to determine what changes and processes took place in shales that were subjected to burial temperatures in the range of 50 to 400 C to predict what changes and processes would occur in shales if they were exposed to heat generated in a HLW repository.

PROGRESS REPORTED PREVIOUSLY

The project began 1 February, 1977. A suite of Cambrian Conasauga shale samples subjected to varying burial temperatures was collected from the ridge and valley province of Georgia, Tennessee, and Alabama. Nearly all mineralogical, chemical, isotopic, petrographic, and structural parameters systematically change from the northwest to the southeast. The changes coincide with increasing depth of maximum burial and therefore with increasing burial temperature. Isotopic temperatures based on the ^{18}O content of illite and quartz, and temperatures estimated on the basis of color alteration of phosphatic fossil fragments, indicate that the burial temperatures range from about 150 to 475 C. Such parameters as illite and chlorite crystallinity, composition of illite and chlorite, 1Md/2M ratio, percentage of expandable layers, potassium-argon apparent age, orientation, flake size, formation of new minerals, etc., vary as a function of increasing temperature. Diagenetic changes occur in the illite, chlorite, quartz, carbonate, feldspar, kaolinite, and mixed layer clay.

ACTIVITIES DURING THE REPORTING PERIOD

Thin sections of the Conasauga shale were studied with the petrographic microscope. The petrographic information will be used as a framework on which to synthesize the wide variety of accumulated data.

The illite-mica in samples from the early diagenesis stage (<150 C) occurs as discrete flakes and plates. Throughout the stages of diagenesis (150 to 250 C), anchimetamorphism (250 to 425 C), and early epimetamorphism (>425 C) this shape is maintained although the crystals become larger, either by growth or aggregation. Slaty cleavage develops by rotation and crystallization, and lenticular domains of chlorite, phengite, and white mica are developed. With increased temperature and metamorphism the lenticular domain becomes thinner and more elongate; cleavage lamellae become more closely spaced. Some original illite-mica is still present.

During the early stages of epigenesis (450 to 500 C), there is pervasive recrystallization and much of the mica recrystallizes into interlocking, subequant packets. New mica is also crystallized and fills tension fractures. The cleavage lamellae and lenticular domains are destroyed. The released iron forms crystals of hematite (or pyrite).

In the Conasauge the recrystallized mica is subjected to a second stage development of crenulations in which the subequant mica packets reform into coarse platelets and the mica systematically rotates into chevron folds and near parallel bands with the plates in adjacent flanks of the folds oriented at progressively smaller angles (differentiated crenulation cleavage). This is accompanied by crystal growth and the growth of new mica in tension fractures. Eventually the mica becomes parallel and a schist texture is developed.

Lenticular domains are not developed during the second stage of crenulation. In part, this is because the silicate mineralogy is simpler. It also suggests that in the early low-temperature stage, when pods develop, thermal changes are more important than physical changes.

In the Conasauga the low-temperature mineral suite contains illite, illite-smectite (i/s), chlorite, potassium and sodium feldspar, biotite, kaolinite, glauconite, quartz, and minor muscovite. Near the end of the diagenetic stage (250 C) potassium feldspar and kaolinite are destroyed, and most of the i/s is converted to illite and chlorite. Biotite, sodium feldspar, and glauconite do not appear to have been affected during diagenesis. During the latter part of the diagenetic stage and the anchizone stage, illite and biotite enter into the reaction and green mica (phengite), white mica, and chlorite are formed.

Potassium-argon analyses of secondary calcite veins in the limestones showed that much of the excess argon released by heat was concentrated in these veins.

The possible use of the scanning laser acoustic microscope for determining the void space in shales was investigated. Samples have been prepared, and arrangements were made for a preliminary examination.

FUTURE ACTIVITIES

The petrographic and SEM work should be completed next quarter and data synthesis will begin. Work on developing a quantitative method for X-ray analysis of bulk samples will continue. Exchange capacity and hopefully pore-water values will be determined.

WBS 1.3.2

PROJECT: Thermodynamic Properties of Actinides

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (N. Edelstein)

ONWI PROJECT MANAGER: J. B. Moody

OBJECTIVE

The program is investigating the thermodynamic properties of anticipated actinide and fission product ions and the compounds they may form in geologic environments so that their chemical behavior and potential migration in a nuclear waste setting can be assessed with improved capability.

PROGRESS REPORTED PREVIOUSLY

This project started in FY 79. Since that time, electrochemical methods for determining stability constants of trace metals have been developed and tested on model systems. Equipment suited for studies on actinides has been designed and constructed, and the electrochemical procedure has been tested in the radiochemical isolation box.

Additionally, techniques using photoacoustic spectroscopy have been developed to detect trace lanthanide ions, especially Nd^{+3}. The laser-based equipment has been designed, constructed, and tested on dilute aqueous solutions.

Studies of metal complexation with hydroxide have been performed using nonlinear least-squares fitting of data obtained in potentiometric titrations of metal ions with base.

ACTIVITIES DURING THE REPORTING PERIOD

Experimental Survey of the Electrochemical Properties of the Actinides

During the past quarter, testing of the isolation box was completed and the box was sealed. Purification of neptunium solutions was carried out, and studies of the Np(IV) - Np(III) system began.

Initial observations of Np(IV) solutions were made using a mercury film on glassy carbon as the working electrode. The computer-controlled potentiostat was used to control the experiment. Addition of a 1 M CO_3^{2-} solution produced a precipitate, believed to be a mixed CO_3^{2-} and OH^- species of Np(IV). No electrochemical response was observed in this solution, but the voltage may not have been cathodic enough to see complexed Np(IV). The voltage expected for reduction of the Np(IV) carbonate species is near -1.8 V (vs. Ag/AgCl). At pH = 10, the hydrogen reduction wave occurred near -1.8 V. By making the solution more basic, the voltage window showed an increase to nearly -2.0 V, allowing observation of the peak. Reducing the CO_3^{2-} concentration below 1 M may also help by shifting the reduction potential to a more positive value which would be inside the pH = 10 window of voltages. The reduction of Np(IV) carbonate complexes at voltages below -1.8 V in 1 M CO_3^{2-} suggests a fairly large stability constant for the complex.

Construction and Testing of Laser Spectroscopy Equipment

Initial studies of Nd^{+3} in aqueous solution using laser-induced, photoacoustic spectroscopy have been completed. Solution concentrations ranging from 1.0×10^{-2} M to 3.0×10^{-5} M were studied at pH = 3, and they were observed to give linear calibration curves. From these curves, a detection limit for Nd^{+3} at 580 nm of 2.0×10^{-5} M (2σ) was calculated. This value allows the estimation of a detection limit of about 1.5×10^{-7} M for Am^{+3} at 514.5 nm. This estimate ignores the higher laser powers possible at 514.5 nm (>3 W vs. 1.0 W).

Studies using a pulsed dye laser showed that the cell design was not optimal for lasers with beam widths in excess of 1 mm, due to scattered light interactions with the piezoelectric material. To remedy this problem, the sample cells are being shielded with a layer of inert, highly reflective metal. This shield should reduce the background and lower the noise, further reducing detection limits and lengthening the cell lifetime.

Studies of Nd^{+3} complexation with CO_3^{2-} have begun. A spectrum of the $Nd^{+3} - CO_3^{2-}$ complex is shown in Figure 1. The hypersensitive band has shifted to the red and has increased in intensity. Some fine structure (seen earlier in uncomplexed Nd^{+3}) remains.

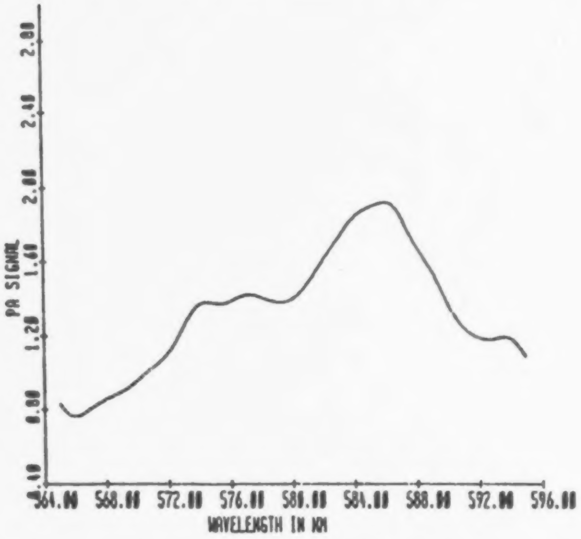

Figure 1. Spectrum of the Nd^{+3} Complexation with CO_3^{2-}.

Detailed Study of Actinide Ion-Hydroxide Interactions

Hydrolysis of UO_2^{2+} is still under study. Results from titrations of UO_2^{2+} with OH^- are being analyzed for solutions containing varying amounts of SO_4^{2-}. Complexation of UO_2^{2+} with SO_4^{2-} appears to be present, but the strength of the complex appears to be low.

Measurements of the Solubilities of Actinide Hydroxides and Complexes--An Automated System

During the past quarter, the counting systems for these measurements were designed, specifications were decided upon for the counters and associated electronic equipment, and purchase orders were placed for some of the equipment. The counting chambers and reservoirs were designed.

WBS 1.3.2

PROJECT: Waste-Rock Interactions Technology (WRIT) Program

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (R. J. Serne)

ONWI PROJECT MANAGER: J. B. Moody

OBJECTIVE

The objectives of the WRIT program are to:

- Identify and characterize mechanisms of waste from radionuclide release and subsequent geochemical interactions with engineered barriers and natural geologic media, e.g., leaching, solubility, and sorption
- Develop and evaluate the effectiveness of models (develop a perspective on applications and limitations of each model) that predict leaching, sorption, and release processes in the repository and surrounding media
- Obtain, through verification studies and documentation, the most acceptable test methodologies for sorption, leaching, solubility limitations, and waste package-geomedia interaction studies
- Support repository site characterization and licensing specifically through data generation, analysis, and predictive model formulation.

ACTIVITIES DURING THE REPORTING PERIOD

Results of X-ray photoelectron spectroscopy (XPS) or auger electron spectroscopy sputter profiling were compared with those of secondary ion mass spectroscopy (SIMS) to evaluate the extent to which certain elements in a reacted glass sputter faster or slower than the average matrix. For most elements (not iron or zinc), either technique could be applied with reasonable accuracy. The fact that SIMS and XPS analyses essentially agree indicates that the glass matrix sputters uniformly; i.e., material is sputtered from the sample surface at a rate proportional to its concentration in the solid.

Although leaching is known to be pH-dependent, the nature and magnitude of the pH effect has not been adequately investigated. Therefore, a leach test study has been performed to determine how pH effects differ in simple glasses, such as fused silica and soda-lime silicate as compared to a more complex borosilicate waste glass. The results indicate dissolution inconsistencies between silicate and borosilicate glass compositions. The mechanistic implications are that dissolution kinetics change dramatically as the former composition of glass changes from a primarily silicate-based matrix to a borosilicate matrix. Thus, leach results of simple glasses should not be used indiscriminately to predict the leaching characteristics of borosilicate waste glass. These results also indicate the leading role pH and subsequent glass constituent hydrolysis play in the dissolution process.

Static tests of 76-68 doped glass beads were performed at 25 and 75 C in leachates of deionized water, 0.03 M sodium bicarbonate, and WIPP B brine. In general, leaching is highest in a sodium bicarbonate solution for all of the nuclides except Tc, where no clear dependence on leachate is evident. The strongest effect is for U, where the 341-day release is one to two orders of magnitude higher in bicarbonate than in deionized water or brine. Releases in WIPP B brine and water are not substantially different.

Uranium adsorption on SiO_2 is being studied at LBL using a combination thermodynamic and adsorption model. Use of the combined models has (1) aided in eliminating ion exchange as the dominant uranium adsorption mechanism at pH >6; (2) helped identify a possible mechanism for uranium adsorption at pH >6; and (3) more accurately fit the experimental data, regardless of

BEST DOCUMENT AVAILABLE

the actual adsorption mechanism. Geochemical sorption models such as this one should be able to predict radionuclide solution concentrations with much more confidence than predictions using a single retardation factor for radioelements having complex chemistries.

A study conducted as LASL showed that plutonium adsorption K_d values for granite decrease with increasing Pu concentration at Pu concentrations below the precipitation region ($<5 \times 10^{-9}$ M). Indications are that Pu may precipitate from granite ground water at Pu concentrations near 3×10^{-9} M, which for ^{239}Pu is only about three times the maximum permissible concentration (5×10^{-6} µCi/ml or 1×10^{-9} M). Studies at RHO indicate reducing ocnditions in basalt environments significantly reduce Np and Tc mobility. Neptunium was adsorbed from the Grande Ronde formation ground water by altered basalt and its secondary minerals both with and without hydrazine (a reducing agent added to simulate repository conditions) in the system. However, the Np concentration in contact with altered basalt was lower by an order of magnitude with hydrazine than without it. Analysis of the final technetium concentrations in contact with basalt, altered basalt, and secondary minerals showed that hydrazine was the only significant parameter (95 percent level) associated with technetium adsorption. Without hydrazine, K_d (Tc) values ranged from 0 to 6 ml/g; with hydrazine, the K_d values ranged from 150 to >400 ml/g.

Previous reports have indicated that in dilute $CaCl_2$ solutions of pH 4 to 7, neptunium exists as Np(V) under oxic conditions. To better understand neptunium solution behavior, experiments were begun to measure the solubility of $NpO_2OH(s)$ over a wide pH range. One general observation in this study is that the pH values of samples initially at a higher pH tended to decrease with time. The decrease in pH was associated with a corresponding increase in Np concentration. The change in pH is most likely caused by alpha radiolysis and nitric acid production. There are implications that such acid production may occur within disrupted waste packages, but experiments with all components present are needed to assess the significance on overall nuclide release from the package.

Careful measurement and control of redox potentials are necessary for meaningful solubility determinations of redox sensitive elements. Questions have been raised in the past about the reliability of platinum electrode measurements in unpoised or weakly poised systems. The validity of Pt electrode measurements has been studied in regard to technetium. Based on these studies, the Pt electrodes are poised by Fe(II) concentrations as low as $\sim 10^{-6}$ M, and thus, Eh measurements appear to be valid.

Efforts have focused on characterizing the solid phase, emphasizing surface and materials present within fractures of UO_2-doped 76-68 glass, from a series of minicanister tests. Based on thermodynamic calculations, the basalt ground-water concentration data lie close to the assemblage of albite, analcime, and montmorillonite. The association of these phases with basalt ground water may deserve further examination as a possible dissolved silica- and pH-controlling mechanism. The increase in silica and alkali content of solutions appears to be a function of time. The trend is toward the albite stability field, which implies that possible albitization of some bentonite backfill components during the thermal period should be considered in backfill evaluations.

Currently, emphasis is on completing the literature review of models applied to the leaching of glass. So far, diffusion is one of the most common processes cited, although it may not be important to the predicted release of radionuclides from glass over the period of interest (thousands of years). The surface-area-to-volume ratio sometimes appears as a primary variable, but its effect is usually seen to change pH which then affects leach rate. So far, the review supports assumptions that corrosion rates need to be characterized in terms of temperature, pH, and radiation field, and that solubility effects need to be better understood.

A list has been developed to determine priorities for designing experiments among the radionuclides whose geochemical behaviors in the repository are of primary importance in evaluating the long-term safety of deep geologic repositories. The list shown in Table 1 is based on the isotopes that have commonly dominated the radiologic consequences of various repository risk assessments. Primary ranking was based on the frequency with which a particular isotope was found to dominate or significantly contribute to the total dose consequences, the absolute magnitude of the isotope-specific dose, the ratio of the dominant isotope dose to the next most significant isotope, and the range of conditions over which it dominated the result.

Table 1. Radioelements of Importance to Long-Term Safety of Geologic Repositories Containing Spent Fuel.(a)

Primary Group		Secondary Group(c)	
(b)Iodine	(^{129}I)	Strontium	(^{90}Sr)
Technetium	(^{99}Tc)	Cesium	(^{137}Cs)
Americium	(^{237}Np), ^{233}U, ^{299}Th, ^{225}Ra	(b)Plutonium	(^{240}Pu)
Neptunium		(b)Thorium	(^{226}Ra)
(b)Uranium	(^{226}Ra), ^{234}U, ^{210}Pb, ^{210}Po	(b)Radium	
(b)Plutonium			
(b)Carbon	(^{14}C)		

(a) Primary isotope or primary daughter isotope in parentheses, secondary daughters following.
(b) Eliminated or greatly reduced significance for reprocessed and/or high-temperature process HLW-form isotope inventory.
(c) Only for extreme conditions of human intrusion.

Three sets of data from PNL 76-68 glass leach tests were modeled using EQ3. The solution data used resulted from the static leach tests in deionized water for 26, 56, and 91 days at 90 C. Preliminary results show that the solution is undersaturated with amorphous silica (natural glass) but is at saturation with quartz. As the solution cools at 25 C, it becomes sequentially saturated with the other forms of silica, i.e., chalcedony, cristobalite, and finally amorphous silica. Furthermore, EQ3 results suggest that with cooling other minerals may act as concentration-limiting phases for other elements in solution. These minerals are analcime (for Na, Si, and Al), smithsonite (for Zn), albite (for Na, Si, and Al), laumontite (for Ca, Si, and Al), and ferrous oxide (for Fe; $E^H = -0.3V$). Not only will these minerals affect the solution concentration of elements present in their structure, but newly formed minerals will serve as sorptive substrates for ions in solution and thus may affect the complete solution chemistry.

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WBS 1.3.2

PROJECT: Uranium Disequilibrium Dating of Ground Water

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (M. Michel)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective of this study is to further develop the uranium disequilibrium method as a tool for dating ground waters ranging from 50,000 to 100,000 years old. This work is primarily directed toward understanding the role of alpha recoil in releasing ^{234}U to the ground water.

ACTIVITIES DURING THE REPORTING PERIOD

The large radius mass spectrometer used for this work was extensively reconfigured to meet other needs, leaving it unavailable for this work.

FUTURE ACTIVITIES

It is anticipated that analyses of the remaining water samples will be completed without further interruption. Also, work is beginning on the injection experiment.

WBS 1.3.2

PROJECT: Helium Dating of Ground Water

PRINCIPAL INVESTIGATOR: Savannah River Laboratory (SRL) (I. W. Marine)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

Samples from several wells which are in proximity will be dated using helium accumulation methods. These samples should give similar age dates because of the close proximity of the wells. If there is substantial variation, the method will need to be reevaluated.

ACTIVITIES DURING THE REPORTING PERIOD

The paper "The Potential Use of Radioactive Decay Products for Dating Ground Water" was presented at the Annual National Meeting of the Geological Society of America in Atlanta, Georgia, on 20 November, 1980.

The paper "Comparison of Laboratory, in Situ, and Rock Mass Measurements of Hydraulic Conductivity of Metamorphic Rock at the Savannah River Plant Near Aiken, SC" was accepted for publication by the journal Water Resources Research. The rock mass measurements involve the use of helium as a ground-water dating technique.

WBS 1.3.2

PROJECT: Osmotic Effects of Clay

PRINCIPAL INVESTIGATOR: Savannah River Laboratory (I. W. Marine)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective is to determine the effects of natural osmotic membranes on natural hydraulic gradients in argillaceous formations.

ACTIVITIES DURING THE REPORTING PERIOD

Work has essentially stopped.

WBS 1.3.2

PROJECT: Effects of Organics in Deep Ground Water

PRINCIPAL INVESTIGATOR: Battelle Columbus Laboratories (J. L. Means)

ONWI PROJECT MANAGER: J. B. Moody

OBJECTIVE

The objective of this program is to fully evaluate the possibility that organic complexing agents from a variety of sources, including the ground water, the repository rock, or the waste itself, may form strong complexes with certain radionuclides and significantly increase radionuclide transport rates from the repository.

PROGRESS REPORTED PREVIOUSLY

This program was initiated in February, 1979. Major findings since then include the following: (1) ethylenediaminetetraacetic acid (EDTA) was identified in eight different ^{238}Pu-contaminated trench leachates from the Maxey Flats radioactive waste burial grounds in Kentucky; (2) the effect of humic and fulvic acids, carbonate, and bicarbonate on U_3O_8 dissolution rates has been experimentally measured; (3) a number of organic acids and phenols have been detected in ground-water samples from Hanford, Washington, and the Finnsjön and Sternö areas of Sweden; (4) mineral and water radionuclide partitioning analyses have been conducted to determine the effect of temperature (25 to 200 C) and oxalic acid content on the adsorption of cobalt, strontium, cesium, and uranium onto kaolinite. Results to date show that systems containing oxalic acid exhibited even greater metal adsorption by kaolinite than systems lacking oxalic acid. Also of interest is that the Kd for strontium and cobalt with kaolinite actually increased with increasing temperature from 100 to 200 C at pH 5 to 6 under mildly reducing conditions.

ACTIVITIES DURING THE REPORTING PERIOD

Research is being conducted in three separate tasks: (1) a laboratory analysis of actinide-humate complex characteristics, including the strength and colloid characteristics of such complexes; (2) mineral and water radionuclide partitioning experiments are being conducted to evaluate the effects of organic ligands on radionuclide migration rates as a function of temperature, pH, and oxidation-reduction potential; and (3) six additional ground-water samples from Sweden are being analyzed by gas chromatographic-mass spectrometric (GC-MS) procedures for ligands, and the humic substances in these samples are being isolated, purified, and chemically characterized.

Actinide-Humate Complex Characteristics

In some 200 separate experiments conducted to date, the colloid characteristics of complexes of humic acid (HA) and fulvic acid (FA) with either uranium, thorium, americium, plutonium, neptunium, sodium, calcium, aluminum, Fe^{2+}, or Fe^{3+} at pH 3.5 to 9.0 have been evaluated. The experiments consist of adding a known amount of soluble metal salt (usually either the nitrate or chloride salt) to a given concentration of purified HA or FA dissolved in water. Three reaction units containing identical metal and organic acid contents are then pH-adjusted, using either HCl or NaOH, to pH 3.5, 6.0, or 8.5. In certain reaction units, a dark brown flocculant is formed during the first several hours of standing. The solutions are agitated for 24 hours and then filtered through a 0.22 μm membrane. Dissolved organic carbon and metal contents of the filtrates are measured to determine the extent of HA or FA and metal flocculation.

Selected results from experiments conducted this past quarter are shown in Figures 1 and 2.

BEST DOCUMENT AVAILABLE

Figure 1 shows the effects of 900 ppm sodium, 50 ppm calcium, 10 ppm uranium, and 10 ppm thorium on HA solubility. The starting HA concentration was 37 ppm. Thorium was observed to exert the greatest effect on HA flocculation, with nearly 90 percent of the HA precipitating in the presence of 10 ppm thorium at pH 4.4. The 10 ppm uranium removed approximately 75 percent of the HA at pH 3.7. The 50 ppm calcium had a weaker effect than thorium or uranium, but still stronger than the 900 ppm of sodium. Flocculation was strongly pH-dependent, increasing at decreasing pH.

Figure 2 shows similar results for FA. Again thorium and uranium had a greater effect on FA solubility than calcium or sodium, but the metal concentrations required to cause the same extent of flocculation were greater. The 50 ppm thorium removed close to 90 percent of the FA at pH 3.9. The 50 ppm uranium removed 71 percent of the FA at pH 3.6. The 100 ppm calcium removed only 10 to 20 percent of the FA at pH 4 to 8, and the 1,000 ppm sodium had virtually no effect on FA solubility.

These results are important because they suggest certain metals form insoluble complexes with HA and FA, especially under acidic conditions. Insoluble complexes may not be able to migrate through the minute interstices of the geologic medium in the deep repository environment. Thus HA and FA, which are generally thought of as radionuclide mobilizing agents, may actually serve as radionuclide immobilizing agents in certain physicochemical environments.

These experiments are being continued. The flocculation of HA and FA by other metals such as plutonium, americium, neptunium, aluminum, Fe^{2+}, and Fe^{3+} has been examined, and the results are currently being tabulated. Also, many experiments using lower HA and FA starting concentrations have been conducted and will be reported next quarter.

Radionuclide Partitioning Experiments

Princeton University continues its studies on the adsorption of strontium, cesium, cobalt, and uranium by different minerals in the presence of organic acids from 25 to 200 C. In addition, an analysis of the thermal breakdown of organic acids as a function of temperature has been initiated. New results should be available next quarter.

Organic Compounds in Ground Waters from Sweden: GC-MS Analysis

Six ground-water samples from the Finnsjön and Sternö areas of Sweden were extracted into methylene chloride and derivatized using 10 percent BF_3 in MeOH for 15 min at $\sim$150 C in a sealed ampoule. Methyl esters produced during derivatization were extracted into chloroform and separated by GC-MS using a 30 SE-52-(methyl silicon)-coated glass capillary column temperature programmed from 40 to 270 C at 4 C/min. Few carboxylic acid methyl esters were identified, and those present were in low concentrations. The samples from Sternö borehole #4, 232 m, Sternö borehole #4, 407 m, and Finnsjön borehole #5, 382 m, contained little or no methyl ester. Six identifiable methyl esters were found in the sample from Finnsjön borehole #4, 562 m, the most prominent of which was the dimethyl ester of hexanedioic acid, present in a concentration of about 10 ppb. The other methyl esters were present in $<$ 1 ppb concentrations. Ground waters from Finnsjön borehole #5, 382 and 494 m levels, were similar, containing numerous fatty acids in trace concentrations, plus about 5 to 10 ppb of hexanedioic acid.

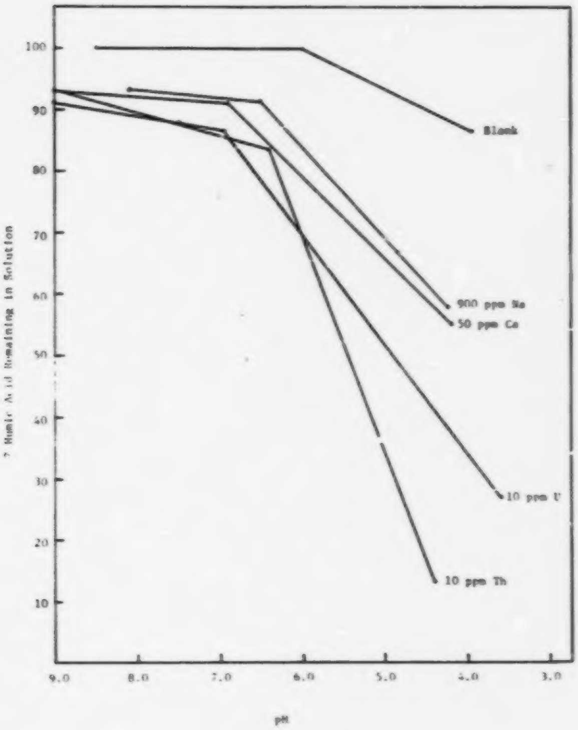

Figure 1. Effect of Different Metals on Humic Acid Solubility as a Function of pH.

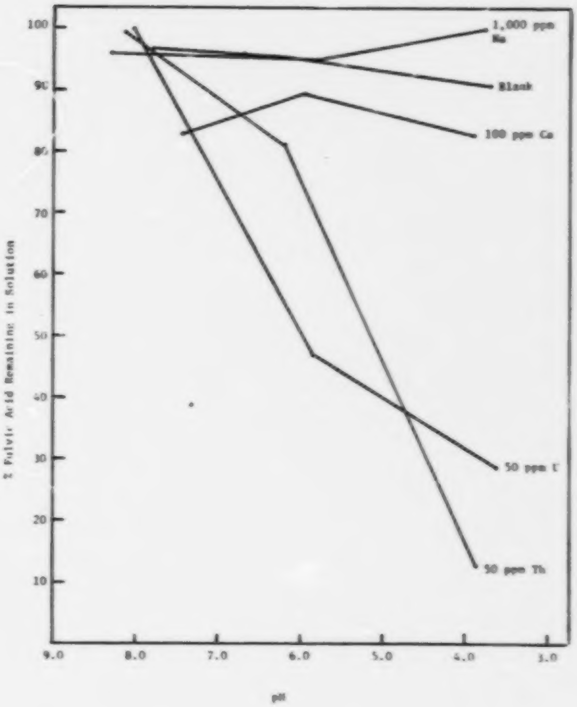

Figure 2. Effect of Different Metals on Fulvic Acid Solubility as a Function of pH.

WBS 1.3.3

PROJECT: Geologic Project Manager Program--
Salina Basin

PRINCIPAL INVESTIGATOR: Stone & Webster
Engineering Corporation (D. S. Pierce)

ONWI PROJECT MANAGER: R. R. Nicks

OBJECTIVE

The objective of the GPM program for the Salina Basin is to plan and manage a systematic investigation of the geologic and hydrologic characteristics of the bedded salt deposits and their enclosing rocks within the basin. This investigation will provide fundamental information necessary to evaluate the basin as a whole, and areas within it, for nuclear waste repository siting.

PROGRESS REPORTED PREVIOUSLY

The program was initiated on 21 July, 1977. A regional geological characterization was undertaken of those portions of the Michigan and Appalachian Basins underlying Michigan, Ohio, and New York. The regional study consisted entirely of a survey of the available technical literature. It was supplemented in New York and Ohio with an extensive compilation of the stratigraphy from an examination of geophysical logs from hundreds of oil and gas wells. A computer program was developed and applied to central New York for modeling multidensity ground-water flow. The principal result of these studies was the identification of areas in New York and Ohio that appear to comply with site-qualification criteria. A program was prepared outlining necessary further investigations.

ACTIVITIES DURING THE REPORTING PERIOD

A study was undertaken of whether, and under what conditions, fractured salt heals naturally. The investigation consists of a review of the pertinent technical literature and visits to three salt mines. By the end of the quarter the study had revealed very little research directed specifically at the fracture-healing phenomenon and that natural fractures in salt are uncommon.

FUTURE ACTIVITIES

A final report on salt fracture healing will be submitted during the third quarter of FY 81.

WBS 1.3.3

PROJECT: Paradox Basin Geologic Exploration

PRINCIPAL INVESTIGATOR: Woodward-Clyde Consultants (WCC) (F. R. Conwell)

ONWI PROJECT MANAGER: N. A. Frazier

OBJECTIVE

The objective is to plan and conduct geologic work required to identify, investigate, characterize, and license a repository in salt.

PROGRESS REPORTED PREVIOUSLY

This project began on 30 August, 1977, and includes drilling support to USGS, a vertical seismic profiling (VSP) program, and geologic siting investigations. The USGS drilling program has been completed; site restoration is ongoing. The VSP program is in its second phase and nearing completion. The first phase of the siting investigation has been completed.

The second phase, now under way, involves sea-level siting investigations in four study areas: Elk Ridge, Gibson Dome, Salt Valley, and Lisbon Valley. Studies reported previously have included geologic mapping; seismic monitoring; aerial and ground reconnaissances and evaluations of structure, physiography, topography, Quaternary deposits, and geomorphology; hydrogeologic and geotechnical testing; and a borehole drilled in the Gibson Dome study area.

ACTIVITIES DURING THE REPORTING PERIOD

Hydrogeology

Coring activities at the Gibson Dome No. 1 (GD-1) boring were completed in early January, 1981. Total depth was 6,384.3 feet, and the hole bottomed in the Ouray limestone of late Devonian and early Mississippian age. All core has been logged and photographed. The following intervals were chosen for drill stem testing (DST) in the Mississippian stratigraphic section: DST No. 23--6,194 to 6,384 feet RKB (rotary Kelly bushing); DST No. 24--6,093 to 6,225 feet RKB; and DST No. 25--5,917 to 6,095 feet RKB. The three drill stem tests were successfully completed; all three zones produced brine water. Samples were collected for the entire suite of traditional and isotopic geochemical analyses. Static reservoir pressures for all three test intervals were approximately 2,400 psi, and flow rates for the intervals ranged from 20 to 80 gallons per minute.

Hydrogeology activities centered on preparing the hydrogeology sections of the Gibson Dome Completion and the Area Characterization Reports. Geochemical sampling of three oil wells in Lisbon Valley which produce water from the Leadville Formation was also completed.

Geotechnical Engineering

The geotechnical engineering activity included further analyses of geotechnical drill stem test results from borehole GD-1; these results and interpretations will be presented in the Gibson Dome volume of the Area Characterization Report. Laboratory mobilization for geotechnical and hydrogeological laboratory testing was nearly completed. Geotechnical testing includes a variety of uniaxial and triaxial creep tests on salt (halite) samples from Salt Cycle 6.

Hydrogeological tests include permeability tests on samples from all significant formations penetrated by the GD-1 borehole. Four-inch diameter GD-1 core will be undercored to a 3-inch diameter in two orientations, parallel to and perpendicular to the core axis; thus, permeability in both the vertical and horizontal directions will be measured in the laboratory.

Stratigraphy

The main activity of the stratigraphy group this quarter has been to prepare the text and figures for the Area Characterization Report. The text for the Regional, Gibson Dome, Lisbon Valley, and Elk Ridge volumes is undergoing review. Figures include structure contours on top of candidate salt beds; depth to candidate salt beds; isopachous maps of candidate salt beds; and cross sections, geologic maps, and maps showing total shale thickness above and below salt.

Geomorphology and Quaternary History

Efforts of the geomorphology and Quaternary history geology staff during this quarter have concentrated on (1) submitting samples collected during the 1980 field season to appropriate laboratories for analysis, and (2) the initial preparation of the Area Characterization Report. In early March, 200 soil samples were submitted to the laboratory for analyses of particle size and carbonate content. Six samples of carbonate rinds that developed on cobbles were sent for uranium-thorium dating. Five samples were sent also for 14 C dating. Thiry samples of carbonate soil and five samples of snail shells have also been submitted for amino acid analyses.

Writing and figure preparation for the Area Characterization Report began in February. Longitudinal and cross-stream profiles have been constructed along Indian Creek in the Gibson Dome area and along Cottonwood and Dry washes in the Elk Ridge area. A Quaternary geology map of the Gibson Dome area has been submitted for drafting. A photogeologic map of Quaternary deposits in the Lisbon Valley area is completed and one for the Elk Ridge area is near completion. The first draft of the text for the geomorphology and Quaternary geology section of the Lisbon Valley and Gibson Dome reports has been completed, and the Elk Ridge text has been started.

Structural Geology

The structural geology group continued examining the structural data obtained to date, analyzing new data, and compiling reports. Data gathered during fault mapping activities of the last three quarters were organized and analyzed for characteristics that could be incorporated into the Elk Ridge and Gibson Dome Area Characterization Reports. Cross sections of the Lockhart Basin area were examined for structural findings, and some of the existing seismic lines in the area were selected for interpretation. The 1:125,000 fault compilation has been revised to incorporate the results of last year's mapping and will be split up into several larger scale figures in the Area Characterization Report.

Literature on collapse features in the Four Corners area was consulted in order to assess comparative mechanisms for the collapse features in the Paradox Basin. A summary of the literature analysis was written, and parts of it will be incorporated into the Elk Ridge and Gibson Dome Area Characterization Reports.

Seismology

Seismological efforts this quarter focused on the operation of the microearthquake networks, analysis of the resulting data, and the writing of the Area Characterization Report. On 23 February, 8 stations of the 12-station Salt Valley network were removed after operating for 6 months. Four stations south of Moab, principally located in the vicinity of the Colorado River and Shafer Basin, were retained to become part of the long-term network. The latter now consists of an 11-station Gibson Dome network and a 5-station Elk Ridge network.

The much larger Gibson Dome network reflects continued interest in the seismic zone aligned along the Colorado River. The evidence to date suggests that the microearthquakes along the river are being induced by rapid declines in the river stage. Microearthquake activity in the previous quarter was typically at a low level and scattered. All observations of seismic activity to date suggest that, with the exception of the concentrated activity along the Colorado River due to a possible triggering influence, microearthquake activity is low-level, diffuse, and confined to the Precambrian basement or deeper. This is totally consistent with the historical seismicity record and views of the tectonic stability of the Colorado Plateau interior.

Energy and Minerals

Work on the energy and minerals activity was concentrated on organizing and preparing the Area Characterization Report.

Tectonic History

The tectonic history activity continued with preparation of the figures and text for the Area Characterization Report. Seven paleotectonic maps of the Colorado Plateau and adjacent regions were compiled for the Cenozoic era. These depict the distribution of sediments, basins, flexures, active faults, uplifts, volcanic centers, dikes, and fluvial systems for each of the time intervals.

FUTURE ACTIVITIES

During the next quarter, all activities will be concentrated on completing the text and figures for the Area Characterization Report and the Location Selection Report.

WBS 1.3.3

PROJECT: Paradox Basin Studies

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, Denver, Colorado (R. J. Hite, Coordinator)

ONWI PROJECT MANAGER: N. A. Frazier

GEOLOGY

(R. J. Hite)

OBJECTIVE

The objective is to conduct geological studies in the Paradox Basin to determine which one, if any, of the many salt-core anticlines in the basin should be investigated as a potential site for a repository.

PROGRESS REPORTED PREVIOUSLY

The project began in 1978 under the Office of Waste Isolation (OWI-Union Carbide). Cuttings from Salt Valley drill holes DOE No. 1 and No. 2 were analyzed for bromine by X-ray fluorescence. Plots of these data show that both holes penetrated the same halite bed which is overturned and nearly vertical. A method was developed to determine the water content of halite rock. This involves dissolving the halite sample in methanol and then determining the amount of water in the methanol using a Karl Fischer titrator.

A methodology for determining the chemical composition of the brine inclusions in halite rocks is being developed. The distribution of trace bromine in halite from DOE No. 3 indicates this hole penetrated the same bed found in DOE No. 1 and No. 2 and that it is also overturned at this location. The determinations of water-insoluble material in the halite rock of DOE No. 3 show that it is very low, averaging about 1.5 weight percent. X-ray diffraction (XRD) examination of these residues show that they generally consist of about 95 percent anhydrite, with the remainder made up of quartz, dolomite, calcite, and trace amounts of illite.

A longitudinal section through the Salt Valley anticline shows that the caprock overlying the salt is sealed off to the northwest by a thick cover of Mancos shale. Additional geologic barriers to hydrologic flow paths from the caprock are the deep and structurally closed synclines flanking the structure. Pyrolysis fluorescence (PF) work, completed in the Salt Valley samples, shows that only very small amounts of hydrocarbons are generated by additional thermal maturation. Clay mineralogy for Salt Valley is finished and shows the clays have low-exchange capacity and no structural water.

Table 1. Results of Analyses of Samples from Salt Valley Cores.

Sample Number	Core Depth, ft	Gas Content, cc/g	Composition		
			Methane, percent	Nitrogen,(a) percent	Carbon Dioxide
3-102	570	0.02	0.7	<1	balance
3-103	881	0.1	0.5	<0.5	balance
3-104	1055	0.009	1.7	<1	balance
3-105	1423	<0.001	ND(b)	ND(b)	ND(b)

(a) Computed by subtracting background nitrogen as determined by oxygen ratio measurement.

(b) Not detected: detection limit for nitrogen is approximately 10^{-4} cc/g, detection limit for methane is approximately 10^{-6} cc/g, and detection limit for CO_2 is approximately 10^{-5} cc/g.

ACTIVITIES DURING THE REPORTING PERIOD

Work was concluded on developing methods to analyze gases occluded in halite rock. The methods appear quite satisfactory for future analyses. Test samples of halite from Salt Valley, which were analyzed by this technique, had very low gas contents. Results of these analyses are as shown in Table 1. This same methodology will be used on samples of halite rock from Gibson Dome.

Experiments concerning the potential problem of chemical bonding tieing up water in the system methanol + NaCl + H_2O showed that this is not a problem in determining H_2O in halite samples. All of the H_2O added to static systems of methanol + NaCl + measured amounts of H_2O was recovered.

Sampling of Salt 6 in Gibson Dome No. 1 was completed. XRD analyses of these whole rock samples were finished, and these data are being plotted. All of the insoluble residue work on this same set of samples has also been completed. The marker beds above and below Salt 6 are being sampled, and these samples will be used for both XRD and PF analyses. Work on the clay mineralogy of these samples should start in the next quarter.

Sampling has begun on the potash deposits in Salt 13 and 18 in the Gibson Dome core. The cores have been halved and will next be quartered so that the necessary chemical analyses can begin.

In fitting the lithologies of the marker bed above Salt 6 with the various geophysical logs run in Gibson Dome No. 1, it was discovered that almost 30 feet of core was lost in this critical interval. The actual intervals of loss are being pinpointed by fitting lithologic units in the remaining core to appropriate intervals of geophysical log response.

FUTURE ACTIVITIES

During the next quarter, the following activities will take place.

1. Chemical analyses of the potash deposits in Salt 13 and 18 at Gibson Dome.
2. Clay mineralogy of insoluble residues in Salt 6 and the confining marker beds at Gibson Dome.
3. Determination of the H_2O content of halite rock in Salt 6 at Gibson Dome.
4. Analyses of occluded gases in halite rock at Gibson Dome.
5. Preparation of the Salt Valley volume for the Area Characterization Report.

HYDROLOGY
(M. S. Whitfield)

OBJECTIVE

The project has two goals: (1) reconnaissance definition of the hydrology of the Paradox Basin in Colorado and Utah, and (2) definition of the hydrology of a site in Salt Valley, Utah.

PROGRESS REPORTED PREVIOUSLY

The Paradox Basin hydrologic project began in November, 1977. In the previous quarter, project reports were in various stages of completion and review.

ACTIVITIES DURING THE REPORTING PERIOD

The reconnaissance reports on the Green River-Moab area, hydrology for the Moab-Monticello area, well-testing for wells DOE Nos. 4 through 9, hydrology for the Blanding-Durango area, hydrology of the Dolores River area, and the San Miguel area are in various stages of review and revision.

FUTURE ACTIVITIES

During the next quarter, the reconnaissance reports on the Green River-Moab area and the hydrology of the Moab-Monticello area will be prepared and submitted to the DOE.

Colleague review of the two remaining reconnaissance reports and the one well-testing report will be completed, and revisions and organizational changes suggested by reviewers will be incorporated before submittal to the DOE.

ELECTRICAL AND ELECTROMAGNETIC SURVEYS
(R. D. Watts)

OBJECTIVE

The objectives are (1) to investigate specific sites in the Paradox Basin (Salt Valley, Gibson Dome, Elk Ridge) for possible structural, material, or hydrologic difficulties for long-term waste disposal, and (2) to evaluate the effectiveness of various geophysical methods for studying structure and hydrology in the Paradox environment and for locating geologic inhomogeneities beyond the range of conventional well-logging probes.

PROGRESS REPORTED PREVIOUSLY

Conclusions from the electromagnetic studies at Salt Valley are: (1) Slingram can detect anomalies that appear to be related to near-surface perched water pods; (2) extremely low-frequency loop-loop soundings revealed no widespread, continuous dissolution at the top of the salt, but there could be small, isolated areas below the detection limit; (3) Schlumberger sounding (DC resistivity) is probably not a good method for investigating caprock above the salt; (4) a helicopter-borne electromagnetic (EM) survey revealed long anomalies within Salt Valley that are probably controlled by caprock lithology; (5) very low frequency (VLF, 15 to 20 kHz) magnetic field tilt and ellipticity data can be used to detect shallow faults covered by the Quaternary eolian deposits that are widespread in the Paradox Basin, (this is a very fast and inexpensive aid in mapping faults and fault extensions); (6) seismic studies showed that the top of the salt at the site of the DOE drill holes in Salt Valley dips toward the northeast limb of the anticline and indicated the presence of blocks of sandstone that have foundered into the salt; (7) geophysical well logs from Salt Valley were successfully interpreted, demonstrating that such logs can give a positive identification of most rock types in an evaporite sequence; (8) hole-to-surface resistivity measurements were successfully made from three source depths in drill hole GD-1, Gibson Dome.

ACTIVITIES DURING THE REPORTING PERIOD

Quantitative interpretation programs for VLF magnetic data were coded. They are presently being debugged and modified for use on the VAX computer. Modeling of VLF anomalies by multiple conductors in a uniform earth will be possible using this program; much better depth and lateral extent interpretation of VLF data should result. The VLF method is used in the Paradox Basin for locating near-surface faults and fracture zones.

Preliminary interpretation of hole-to-surface resistivity data is continuing. A theoretical model has been developed for a drill hole containing metal casing. Results from this model indicate that metal casing can be used as an effective source for hole-to-surface resistivity measurements. This theory still needs to be tested in the field.

FUTURE ACTIVITIES

The following activities are planned: (1) extensive DC electrical survey of the Gibson Dome-Lockhart Basin study area; (2) follow-up VLF surveys at Lockhart Basin, Shay Graben, and Hatch Point; (3) preparation of several reports for submission to ONWI during the third quarter of FY 81; and (4) completion of interpretation for Gibson Dome No. 1 hole-to-surface results.

SEISMIC PROFILING

(A. H. Balch)

OBJECTIVE

The objectives are (1) to evaluate the state of the art of downhole seismic equipment for profile mapping of interbeds in salt; (2) to use seismic geophysical data to characterize and differentiate subsurface lithologies and structural configurations in areas of interest; (3) to obtain a surface seismic profile at the Elk Ridge area which will be tied into the DOE Elk Ridge test well; and (4) to map the Paradox salt in this area, especially for thinning, solution cavities, and faulting, and also the subadjacent strata, including basement in the vicinity of Comb Ridge.

PROGRESS REPORTED PREVIOUSLY

Two vertical seismic profile field sessions were conducted in 1979. Extensive reformatting, editing, analysis, and processing have been performed on these data, with the main objective of improving the signal-to-noise ratio. The desired reflections are very weak compared with the direct arrivals, multiple reflections, and a host of other types of unwanted seismic events. The processing and interpretation have been further complicated by the radiation from secondary and tertiary compressional and shear waves, caused by tube waves that are generated by the source in the source holes.

By means of extensive computer processing, it was possible to detect reflections from a multiplicity of marker horizons at numerous depths in the hole. The dip of these horizons can be estimated by comparing their apparent velocities with calculated apparent velocities for a variety of dips. Some ambiguities remain, because it is often difficult to distinguish compressional modes from shear modes, and an overturned bed can produce reflections with the same apparent velocity as a bed that is right side up.

ACTIVITIES DURING THE REPORTING PERIOD

Computer processing to enhance marker bed reflections at depth and interpretation of the enhanced reflections have been the main efforts during the past quarter. Geometrical interpretation of the attitude of a marker bed is based on the medium velocity and arrival times of up- and down-going seismic events under a homogeneous medium assumption. Many factors affect the interpretation of a marker bed attitude. Two kinds of error sources were studied:

1. The errors estimating dip and depth of a marker bed introduced by the uncertainty of the medium velocity, which somewhat account for the inhomogeneity of the actual medium.
2. The errors estimating the dip and depth of a marker bed introduced by the systematic uncertainty in the arrival times, which partially account for the effect of complex interference patterns of the reflection event.

This error analysis could provide a confidence interval for the final interpretation of the Salt Valley experiments.

FUTURE ACTIVITIES

Interpretation will be completed, and a draft report will be written during the quarter.

REMOTE SENSING

(J. D. Friedman)

OBJECTIVE

The objective of the Paradox Basin remote sensing project is to acquire, process, and interpret geologically a variety of satellite and aircraft image products of the region in order to assess factors in the tectonic and geomorphologic environment that might significantly affect the quality of a nuclear waste repository site. Particular attention will be given to detecting and delineating previously unmapped structures.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.3.3

PROJECT: Permian Basin Geologic Studies

PRINCIPAL INVESTIGATOR: Texas Bureau of Economic Geology (TBEG) (T. C. Gustavson)

ONWI PROJECT MANAGER: G. D. Brunton

OBJECTIVE

The objective of this project, since its inception in mid-1977, has been to characterize the geology and hydrology of the Palo Duro and Dalhart Basins of the Texas Panhandle. Bedded Permian salts within these basins are being studied to determine if they may contain sites suitable for a repository for high-level nuclear waste.

PROGRESS REPORTED PREVIOUSLY

The third year of analysis was highlighted by initiation of a regional basement structural analysis, quantification of geophysical log parameters, analyses of the water content of basin salts, continuation of the petroleum source-rock analysis, hydrogeologic mapping, characterization of cores, genetic stratigraphic facies mapping, climatic-geomorphic monitoring of the Texas Panhandle, and continued investigations of the processes, timing, and rates of salt dissolution. Each study provides a basis for detailed data interpretation and future integration of research elements.

ACTIVITIES DURING THE REPORTING PERIOD

Remote Sensing, Shallow Stratigraphy, and Surficial Analyses

The topical report, *Regional Dissolution of Permian Salt in the Anadarko, Dalhart, and Palo Duro Basins of the Texas Panhandle*, was released as the Bureau of Economic Geology, University of Texas Report of Investigations No. 106.

Erosion monitoring, stream incision, stream morphometric analyses, and salt dissolution studies in the western portion of the Palo Duro Basin in eastern New Mexico were continued throughout this quarter.

Geochemistry and Hydrology

The preliminary identification of clay minerals in the Randall and Swisher cores has been completed, and the facies relationships are now being evaluated.

The computed total dissolved solids (TDS) values for the brines in Palo Duro Basin and the chemical analyses obtained from numerous sources are now compiled and are being incorporated into a manuscript on the deep basin hydrogeology.

Flow through the region drained by the Prairie Dog Town fork of the Red River has been simulated in a preliminary fashion with the computer model FLUMP. A paper has been accepted for presentation at the Geological Society of America discussing this flow system and the geochemistry of the fluids in the contributing aquifers.

Cooperative work with the USGS on the study of fluid inclusions in salt from the Palo Duro Basin, Texas, has been proceeding for nine months. Much of the previous six months has been spent in a series of studies of the behavior of various types of material from the Palo Duro cores under a variety of laboratory sample preparation, dehydration, and water analysis procedures. Both typical, standard analytical procedures, as described in the literature, and atypical, special procedures have been explored. As a result of this work and reviews of the modes of occurrence of water in rock salt and of the scientific literature, it became obvious that most published analytical determinations of water in rock salt from potential nuclear waste isolation sites are misleading, and many are seriously in error, mainly on the low side.

Other than this major finding, a few highlights of the work done recently are as follows:

1. Water loss on heating of pieces of core is exceedingly slow, even in vacuum. Thus a 255 g fragment, which had already lost > 2 weight percent H_2O on heating in vacuum for several hundred hours, was still losing weight, linearly with time, after 72 hours at 300 C and then 160 hours at ± 351 C.
2. Water loss on heating small samples of powdered material is also slow, requiring 1-1/2 hours to reach essentially final weight loss values at both 35 C and 350 C.
3. After heating to 200 C for 48 hours, small samples of silt-rich material gained as much as 0.15 weight percent on contact with normal laboratory air (relative humidity ∿ 50 percent) in a few days.
4. Liquid water, not previously visible in silt-rich areas within a single crystal of NaCl (although presumably present interstitially), was seen to accumulate on the hot side and start to move as a normal fluid inclusion when the sample was subjected to a thermal gradient.

Basin Analysis

Slides previously prepared for visual kerogen analysis were observed for fluorescence under ultraviolet irradiation. The highest percentages of fluorescing material occurred in Oldham, Randall, and Cottle County samples. These samples were previously found to contain favorable kerogen by visual analysis; this work substantiates the earlier findings.

Detailed study of granite wash and interbedded carbonates from Mobeetie Field continued. Petrographic study of granite wash identified chlorite, quartz, feldspar, kaolinite, calcite, iron-dolomite, anhydrite, and celestite authigenic cements.

Faunal description through an algal-mound ressservoir sequence was completed. Algal-mound cores consist of algae-foraminifer wackestone and packstone. Mounds are capped by coral boundstone and encrusting algae-foraminifer wackestone to boundstone. Hydrocarbon production is mainly from porous boundstones and packstones.

Host Rock Analysis

Petrographic analyses of the Glorieta and Upper Clear Fork Formations in the core from the No. 1 Grabb-DOE core test well in Swisher County, Texas, have been completed.

FUTURE ACTIVITIES

In the remaining half of the fiscal year, it is planned to complete the vacuum decrepitation runs on the hemicylindrical samples still on hand, complete optical estimates of free water present as fluid inclusions on those portions of the polished slabs still on hand, and, by having selected samples of such material run by other methods (e.g., at Texas), try to understand better the major limitations on the various analytical procedures for water in salt, as well as to obtain valid determinations of the several varieties of water present in the Palo Duro samples.

WBS 1.3.3

PROJECT: Geologic Project Manager (GPM) Program--Permian Basin

PRINCIPAL INVESTIGATOR: Stone & Webster Engineering Corporation (J. Briedis)

ONWI PROJECT MANAGER: G. D. Brunton

OBJECTIVE

The objectives are to plan, manage, and perform geologic and geotechnical investigations to identify and characterize one or more potential radioactive waste repository sites in bedded salts which underlie the Permian Basin, with initial interest in the Palo Duro and Dalhart Subbasins of Texas, and to provide follow-on support if any site is selected by the Department of Energy for development of a repository.

PROGRESS REPORTED PREVIOUSLY

This project was initiated on 10 July, 1980. Previous work involved subregional characterization studies for the Palo Duro and Dalhart Basins based on available data and published literature on the geology, geophysics, and hydrogeology of the region. In order to identify within the subregion areas suitable for more focused studies, screening specifications were established for minimum depth (1,000 ft), maximum depth (3,000 ft), and minimum net salt thickness (50 ft) in at least one of the seven Permian salt-bearing formations. Oil and gas fields, unsuitable for repository siting,were screened from the subregion. The resulting recommended area was shown in a previous Quarterly Technical Progress Report. The area is large, suggesting that much of the Palo Duro and Dalhart Basin subregion exhibits geological conditions suitable for repository siting. It was determined that identification of smaller candidate areas (on the order of 100 square miles) would require screening using a specification for minimum thickness of individual salt beds.

ACTIVITIES DURING THE REPORTING PERIOD

Subregional characterization and screening activities were completed during the reporting period. The previously reported qualifying area was subjected to further screening using more restrictive specifications for salt geometry (thickness) and subsurface hydrology (dissolution) as follows:

- Thickness--Qualifying areas must be underlain by at least one salt unit having a minimum thickness of 70 ft (including no more than about 15 percent of interbedded nonsalt lithologies).
- Dissolution--The entire area underlain by active dissolution in any of the salt-bearing formations was deferred from consideration.

The thickness specification was applied using preliminary geologic interpretations of geophysical logs from 165 selected wells. The dissolution zone has been described in recent reports by TBEG. By applying these specifications, two qualifying areas were identified, one in the Palo Duro Basin and the other in the Dalhart Basin (respectively the sourthern and northern areas shown on Figure 1).

Preliminary interpretation of geophysical well logs for screening on salt bed thickness identified seven target salt beds that meet the 70-ft-thickness specification. These beds occur within the formations listed below in order of increasing stratigraphic depth:

- Salado Formation
- Seven Rivers Formation
- Upper San Andres Formation
- Lower San Andres Formation (Cycles 3, 4, and 5)
- Upper Clear Fork Formation.

The target beds appear to be continuous over large areas. They display a slight dip and general facies migration from north to south. Thus, only the stratigraphically deeper beds in the north and the shallower beds in the south occur at depths between 1,000 and 3,000 ft. The number, depth, and quality of target beds, therefore, vary across the two qualifying areas. The well-log data strongly indicate that the lower San Andres Cycle 4 salt is the most consistent of the seven target beds in terms of thickness of high quality salt (up to 235 ft). The target bed in the Salado Formation attains a thickness of up to 200 ft of generally good quality salt. The other five units are less thick and appear to display greater variation in quality. This information was used to subdivide the two qualifying areas into four smaller areas and assign to each a priority ranking for further study (Figure 1).

Area 1 is ranked first. It is defined by the cumulative extent of the three target beds in the Lower San Andres Formation, including the Cycle 4 salt which underlies most of the area. Target beds in the Upper San Andres and Seven Rivers Formations also are present in parts of Area 1. Exploration activities in the area will be the most productive due to the multiplicity of target beds that can be penetrated by a single borehole.

Area 2 is ranked second. It is defined by the extent of the target bed in the Salado Formation and is also underlain in part by target beds in the Upper San Andres and Seven Rivers Formations.

Area 3, ranked third, comprises the remainder of the qualifying area in the Palo Duro Basin. It is underlain by the target salt bed in the Seven Rivers Formation and/or the Upper San Andres Formation.

Area 4, in the Dalhart Basin, is ranked fourth. It is underlain by a single target salt bed (in the Upper Clear Fork Formation) which is generally little more than 70 ft in thickness.

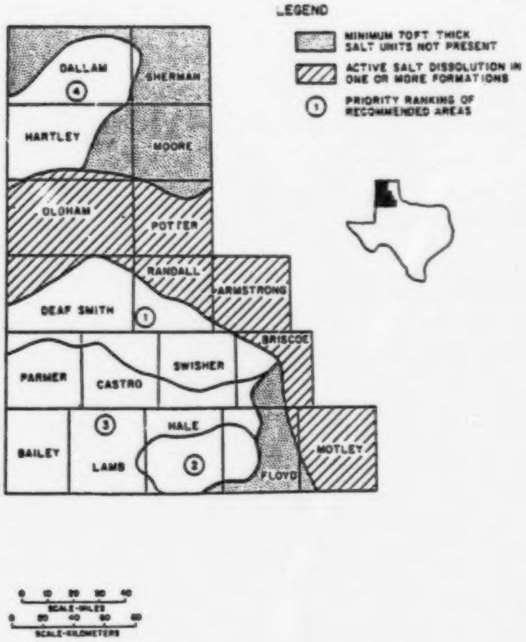
LEGEND
MINIMUM 70FT THICK SALT UNITS NOT PRESENT
ACTIVE SALT DISSOLUTION IN ONE OR MORE FORMATIONS
① PRIORITY RANKING OF RECOMMENDED AREAS
DALLAM
SHERMAN
④
HARTLEY
MOORE
OLDHAM
POTTER
RANDALL
ARMSTRONG
DEAF SMITH
①
PARMER
CASTRO
SWISHER
BRISCOE
BAILEY
③
LAMB
HALE
②
FLOYD
MOTLEY
0 10 20 30 40
SCALE-MILES
0 20 40 60 80
SCALE-KILOMETERS

Figure 1. Areas Recommended for Further Study.

FUTURE ACTIVITIES

The following activities are planned for the upcoming quarter:

- Provide support to the ONWI Recommendation Team as required to identify a location for drilling additional exploratory holes in the Palo Duro Basin during the third quarter of FY 81.
- Begin drilling and testing a stratigraphic test well located in Donley County, Texas.

Drilling and testing of a well in Oldham County is scheduled to begin during the fourth quarter of FY 81.

WBS 1.3.3

PROJECT: East Texas Salt Dome Studies

PRINCIPAL INVESTIGATOR: Texas Bureau of Economic Geology (TBEG) (C. W. Kreitler)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The objectives are to evaluate the potential of East Texas salt domes as hosts for the management of nuclear wastes; to determine whether salt domes and their environs will remain tectonically stable during the active life of nuclear wastes; and to determine whether domes will remain hydrologically stable over the same period of time.

PROGRESS REPORTED PREVIOUSLY

The Bureau began activities in January, 1978. Initial studies concluded that three domes in East Texas (Keechi, Palestine, and Oakwood) merited further study. Since then the Bureau has recommended that Palestine Dome no longer be considered as a candidate dome because of the extensive brining that had previously occurred there. Dome-specific studies have continued on Oakwood and Keechi, as well as generic studies on the rest of the basin.

ACTIVITIES DURING THE REPORTING PERIOD

Basin Stratigraphy

Studies in basin stratigraphy included:

1. Late Jurassic to early Cretaceous Cotton Valley-Hosston clastics--A depositional systems study overlying the thickness, distribution, and relationship to early salt dome growth in the northwestern part of the basin is in progress. Core descriptions (1,000 ft) and thin section analyses are being prepared.
2. Early Cretaceous upper Glen Rose-Paluxy clastics--A study of the interrelationship between depositional systems and growth of salt domes and salt pillows is ongoing.
3. Eocene Wilcox clastics--Net sand and percent sand contour maps have been completed for the Wilcox section in Anderson, Freestone, and Leon Counties around Oakwood, Butler, Palestine, Keechi, Concord, Brushy Creek, Boggy Creek, and Bethel Salt Domes.

Salt Mobilization

The timing and areas of salt dome growth in the East Texas Basin show that (1) regional sedimentation, subsidence, and rates of salt movement have declined from peak rates in the Early Cretaceous, and (2) the loci of salt movement for different intervals show a consistent pattern. Early dome growth (early Cretaceous pre-Glen Rose Formation) concentrated in the southern area of the basin (Oakwood, Keechi, Butler, Palestine, Bullard, and Whitehouse Salt Domes).

Meteoric Hydrology

Cross sections were developed from electric logs showing clean sand (Ro>20 ohm-m) and muddy sands and shale (Ro<20 ohm-m) for the Wilcox group. This information has been used in refining the ground-water flow model. The domes are located in muddy sand and shale areas of the Wilcox group.

Grain size distributions were used to calculate permeabilities. The results were good for the Wilcox clean sands but unacceptable for the muddy sands.

Chemical analyses for sodium, calcium, magnesium, and potassium content have been completed in 36 Wilcox samples.

Geochemistry Around Oakwood Dome

1. C^{14} analyses were checked by duplicating C^{14} analyses.
2. Corrected ages were adjusted with new δC^{13} values. Data now fit better linear pattern.
3. Redox measurements were made by analyzing ground waters for Eh, dissolved O_2, iron, sulfate, uranium, and hydrogen sulfide.
4. Soil CO samples were gathered for δC^{13} analysis. These data are being collected to determine the initial δC^{13} input for C^{14} corrections.

Results of the Oakwood Ground-Water Model

1. Where muds of the Reklaw aquitard are laterally continuous, topography exerts minimal influence on flow within the Wilcox-Carrizo (Wx-Cz) itself and significantly impacts only the rate of leakage across the aquitard.
2. Where muds of the Reklaw become discontinuous, effects of topography can be very important.
3. The portion of the Trinity River south of the Elkhart Graben-Mt. Enterprise fault zone is probably not a major discharge area for the Wx-Ca, contrary to what was thought earlier.
4. The portion of the river north of the fault zone does appear to be a major discharge area, especially along the reach east of Butler Salt Dome, where the Reklaw may be breached by the river.

Deep Basin Hydrology

All water chemistry data have been compiled into tabular and map form. Horizons for which maps are being made are: (1) Nacatosh, (2) Eagle Ford, (3) Woodbine, (4) Goodland and Fredricksburg, (5) Paluxy, (6) Rolessa and James, and (7) Travis Peak and Pettet. No interpretations have been made.

Internal Dome Studies

Fluid inclusions were studied using microscopic examination, modal analysis, and experimental breaching of intracrystalline inclusions. Expanding gases in the salt and caprock indicate inclusion at depths greater than present depths.

Strain data were statistically tested and checked against experimental modeling of diapirs. The stress is likely caused by upward force and may be responsible for the tight seal between each salt and caprock in this core.

Caprock Studies

Efforts this quarter were directed toward obtaining samples of other caprock including Mississippi and Louisiana domes. A study of false caprock over Butler Dome was begun.

FUTURE ACTIVITIES

The following activities will take place:

1. Salt mobilization studies will be expanded to include salt volume calculations, heat flow, decompaction, and mass-balance studies.
2. All major aspects of the internal dome study have been completed. The next quarter will be spent preparing the results for publication and collecting small amounts of miscellaneous data.
3. For the deep basin hydrology task, geochemical data will be computerized and studied statistically, as well as identifying patterns for the mapped horizons.
4. One of the main tasks of the basin tectonics group will be to determine the degree of basement control, if any, on the Mt. Enterprise-Elkhart fault zone.
5. New microseismographs will be installed.
6. The petrographic study of caprock and false caprock will continue.

WBS 1.3.3

PROJECT: Gulf Coast Salt Dome Project

PRINCIPAL INVESTIGATOR: Law Engineering Testing Company (D. E. Pauls)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The overall objective of this Geologic Project Manager program is to identify and rank candidate sites for a waste repository. Other scientific investigations have been established by ONWI to evaluate the geologic and hydrologic framework in the study areas of northwest Texas, Louisiana, and Mississippi. The GPM will use the results of these investigations to arrive at conclusions for dome priorities.

PROGRESS REPORTED PREVIOUSLY

The Geologic Project Manager began activities on 1 July 1977. Subsequent activities included an evaluation of the geologic and hydrologic framework in the area of three salt domes in Texas (Keechi, Oakwood, and Palestine), three in Mississippi (Cypress Creek, Lampton, and Richton), and two in Louisiana (Rayburn's and Vacherie) and provision of a uniform data base for each of the eight potential domes within these areas. Data acquisition and evaluation continued in support of Area Characterization. Deep drilling operations for the Area Characterization phase were completed in Texas and Mississippi. These operations for the Area Characterization phase were completed in Texas and Mississippi.

In all, 222 shallow borings were made in Texas, Louisiana, and Mississippi.

Styrofoam models of the salt stock have been prepared for seven domes, based on purchased and measured gravity data and supplemented by seismic data and well control where available. High-resolution seismic data were used in conjunction with gravity data at both Cypress Creek and Richton Domes to develop detailed analyses of the shallow beds on domal flanks not well recorded by common-depth-point seismic data.

ACTIVITIES DURING THE REPORTING PERIOD

The principal activities conducted during the second quarter of February, 1981, were the planning and preparation of 12 topical reports, 5 special project reports, and 15 well completion reports.

The topical reports are expanded versions of subjects dealing with the fundamental aspects of salt domes and their geological environments, growing out of the Area Characterization phase of this project.

The well completion reports are factual, detailed summaries of the geological and hydrological data collected from the boreholes drilled in support of Area Characterization.

In addition, the final draft of the North Louisiana Area Characterization Report and the first draft of the Appendix for the Northern Louisiana Area Characterization Study were compiled and submitted to ONWI. LETCo also submitted to ONWI an extensive report on borehole plugging which addresses (1) legal liability to plug, (2) technical desirability to plug, (3) hole accessibility, and (4) the estimated cost of plugging.

FUTURE ACTIVITIES

During the third quarter of FY 81, all of the topical reports, special project reports, and well completion reports will have been completed and submitted as final drafts and, following approval, will be prepared as final reports.

WBS 1.3.3

PROJECT: Louisiana Salt Dome Studies

PRINCIPAL INVESTIGATOR: Louisiana State University (J. Martinez, coordinator)

ONWI PROJECT MANAGER: O. E. Swanson

GEOMECHANICS STUDIES

(R. L. Thoms)

OBJECTIVE

The general objective is to monitor and analyze any possible ongoing movement that can be associated with salt domes. Thus, this study deals with the current tectonic stability of Vacherie and Rayburn's Domes in north Louisiana.

PROGRESS REPORTED PREVIOUSLY

Geomechanics studies have included monitoring of any current ongoing movement over Vacherie and Rayburn's Domes with a complementary system of field instrumentation and numerical modeling. These studies include: (1) tiltmeters, (2) precise releveling, (3) core-hole closure monitoring, (4) seismicity monitoring, (5) microseismic monitoring, (6) numerical modeling, and (7) the planning of laser ranging systems.

Of the above-listed seven items, major emphasis has been placed on tiltmeters, precise releveling, and core-hole closure monitoring. Some work also has been performed on microseismic monitoring at Rayburn's and Vacherie Domes, respectively.

Progress reported previously included deactivation of tiltmeters over Rayburn's Dome and numerical modeling of surface movements associated with salt stock movement at depth. Further, it was indicated that core-hole diameter logging data of September, 1980, might be of limited value because unsuitable logging equipment was used.

ACTIVITIES DURING THE REPORTING PERIOD

Core-Hole Closure Survey

The core-hole diameter logging data of September, 1980, was reworked into a usable format. These data are being used in a topical report on core-hole closure which currently is in draft form.

Tiltmeter Data Collection and Analysis

The digitizing of strip chart data is again proceeding. A new system is being developed to allow the relatively rapid transfer of digitally recorded data from tape cassettes to the IBM 3033. A preliminary test of this system was successful. During the next quarter, programs which are now used for preliminary analysis of data from digitized strip charts will be modified to operate on the digitally recorded data.

A preliminary study is under way to analyze one-day averages of tiltmeter recordings, air temperature, soil temperature, and soil resistance. The major purposes of this portion of the study are (1) to prepare and test methods of analysis for use when more complete data are available, (2) to develop a method to identify outliers and a way to deal with these data, and (3) to provide a preliminary analysis of the incomplete data now available.

The computer language, SPEAKEASY (Cohen and Pieper, 1979), is being used for most of this initial analytical program development. SPEAKEASY can be used as a "super desk calculator" to provide access to information stored in the computer. The simplicity of data manipulation and versatility of output in either tabular or graphical form makes SPEAKEASY an efficient language for the development of data analysis procedures. Graphical output is available either to the Tektronix 4051 terminal for interactive plotting and analysis, or to the Varian electrostatic printer/plotter for hard-copy output.

FUTURE ACTIVITIES

Precise releveling will be initiated over the Vacherie Dome, and the core holes at both Vacherie and Rayburn's Domes will be caliper logged for diameter changes. This work will complete field activities planned for precise releveling and core-hole closure studies at these sites.

GEOHYDROLOGY STUDIES

(M. B. Kumar)

OBJECTIVE

The objectives are (1) to determine the hydrologic stability of north Louisiana salt domes, and (2) to study the hydrologic isolation of mined openings in salt domes.

PROGRESS REPORTED PREVIOUSLY

Geohydrology studies have included the drilling of seven exploratory observation wells. A possible saline plume was detected to the east and southeast of Vacherie Dome (no such plume was observed in the vicinity of Rayburn's Dome). Numerical modeling activities have been under way to simulate domal saline plumes. An investigation of possible salt springs in the dome areas has been initiated. Several existing salt mines in the Gulf Coast were studied for leaks.

The chemical and isotopic analyses of the water from the leaks at the Belle Isle, Weeks Island, and Jefferson Island salt mines strongly indicate that the mine brines are formation waters. A similar investigation has been in progress for the Avery Island salt mine. A technique was developed to conduct routine measurements of ±0.002 weight percent water in salt. Measurements of water content of several samples of salt and sandstone inclusions were made. Preparations were begun for isotopic analyses of trace water extracted from salt.

ACTIVITIES DURING THE REPORTING PERIOD

Jefferson Island Mine Flooding Study

The study of the recent flooding of the Jefferson Island salt mine is proceeding well. Relevant published reports are under study. A base map has been prepared to document the locations of petroleum and sulfur wells drilled in and around the collapsed area. Geophysical logs of wells needed for the initial study have been procured from the Louisiana Department of Conservation and other sources. Data on water wells in the area are being compiled from the USGS. Efforts are currently under way to estimate salinities of water in the aquifers adjacent to the dome. Additionally, well logs are being correlated preparatory to constructing geological cross sections and mapping historical dissolution patterns.

Concerning the surficial geological features resulting from the collapse event on Jefferson Island, see Martinez, Kumar, Kolb, and Coleman (1981).

Mine Leak Study

The subsurface leak study of the Avery Island mine has made headway. Some of the mine leak samples were reanalyzed, and the new and old analytical data are being evaluated. For further studies, additional samples of the mine leaks have been received from International Salt Company.

Several log-log plots of bromide and chloride versus other constituents of the mine brines have been prepared and are currently being interpreted in conjunction with other data. The preliminary conclusion drawn thus far is that the mine leaks at Avery Island generally differ from most of the leaks in the Weeks Island and Belle Isle salt mines, and that the Avery Island mine leaks are mostly of meteoric origin.

Surface Water Salinity (Salt Springs) Study

The surface water salinity study was continued with another trip by Institute personnel to the Vacherie and Rayburn's Dome areas. Water samples were obtained from the area northeast of LSU water well V-6, where previous samples had registered anomalously high values of chlorinity. In the Rayburn's area, some water samples were collected from an apparent spring which feeds into Fouse Creek. The concentrations of Na+ and Cl^- in these samples are not too high. This may reflect a dilution effect due to meteoric precipitations that occurred in the area before the samples were collected. Further field activities are planned.

Numerical Modeling of Domal Saline Plumes

Numerical modeling activities pertaining to domal saline plumes are continuing. Work on additional parametric simulations with the saline plumes model continued with the objectives of evaluating the sensitivity of various significant parameters governing solute transport in porous media for relatively long durations of salt dissolutions.

FUTURE ACTIVITIES

The numerical modeling of domal saline plumes will be continued, with emphasis on sensitivity analyses of the significant parameters involved and verifications with ORNL's AT123D model. The future salt spring study will comprise further investigations of the surface waters in the Vacherie area with anomalously high chlorinity values observed during the preliminary examinations. Detailed sampling of the surface waters in the Rayburn's area is also planned. The Avery Island mine leak study will include an appraisal of new data on recently acquired leak samples. Efforts will be made to arrange isotopic measurements on the trace water of salt. The ongoing study of the Jefferson Island min flooding will be completed by integrating all available data.

REGIONAL GEOLOGY

(R. E. Wilcox)

OBJECTIVES

The objectives of this study are (1) to determine the petrology, mineralogy, and geochemistry of salt and caprock from Vacherie and Rayburn's domal cores; (2) to appraise the tectonic stability of salt domes in north Louisiana; and (3) to study the sizes and shapes of Vacherie and Rayburn's Salt Domes, Webster and Bienville Parishes, Louisiana.

The primary emphasis and research efforts will focus on the first objective during FY 81.

PROGRESS REPORTED PREVIOUSLY

Studies of regional structure and stratigraphy of the north Louisiana salt dome basin were completed in previous years, as were several seismic studies of Vacherie Salt Dome, reports on the lithology of salt cores from Vacherie and Rayburn's Domes, and chemical analyses of salt core samples. Mathematical approaches to the inverse-density interpretation of gravity data over salt domes were developed.

Initial detailed studies of Vacherie and Rayburn's core layering using petrographic and geochemical techniques have included dissolution studies of salt and caprock samples, the selection of 161 salt and caprock samples from Vacherie and Rayburn's cores for detailed petrological and geochemical studies, and exploratory atomic absorption analyses of two different salt textures.

Work last quarter emphasized further refinements in analytical techniques to be used on the selected samples of salt and caprock.

Salt core samples are being analyzed with good precision for sodium, calcium, potassium, magnesium, strontium, and $SO_4^=$ on a routine basis in the reorganized geochemistry laboratory. The stability of the atomic absorption spectrophotometer was vastly improved by installing a voltage stabilizer which was recently purchased. The mercuric nitrate procedure for Cl^- was tested and found to be unsuitable. Therefore, a potentiometric method will be tried. Procedures for the potentiometric method of analysis of Br^- have been received from a German salt laboratory and will be tested during the next quarter.

Three six-inch segments of core (salt and caprock cores from Vacherie and Rayburn's Domes) were sent to BPNL for isotopic studies.

FUTURE ACTIVITIES

Work will continue on the petrology and geochemical analyses of the core samples previously selected from Vacherie and Rayburn's Salt Domes.

QUATERNARY STUDIES

(C. R. Kolb)

OBJECTIVE

The objectives have been (1) to determine whether the Quaternary has been lifted out of place above Rayburn's and Vacherie Domes by upward movement of the salt since deposition of these sediments between 5,000 and 500,000 years ago, (2) to provide insights concerning the hydrologic stability of the upper portions of the domes as evidenced by dissolution and subsidence and/or collapse during Quaternary time, and (3) to estimate the effects of erosion above the domes during the next 250,000 years.

PROGRESS REPORTED PREVIOUSLY

Incomplete studies to date have shown: (1) no evidence of tectonic uplift over Vacherie Dome during Quaternary time; (2) possible minor dissolution and subsidence above Vacherie and more significant dissolution over Rayburn's during the Quaternary; and (3) that a maximum of 120 feet of erosion can be expected at both sites during the next 250,000 years.

Borings (20 to 200 feet deep) above the domes have penetrated unusually deep Quaternary deposits. These deposits suggest dissolution and collapse or subsidence of the upper part of the domes--a minor amount over Vacherie Dome during the Quaternary, and more than 100 feet over Rayburn's Dome during this period. Complicating matters are deep "anomalous" sands beneath the known Quaternary at Vacherie and a thick calcitic boulder zone above the anhydrite caprock at Rayburn's. It is uncertain whether these strata are of Quaternary or pre-Quaternary age.

Work during the preceding quarter involved (1) completion of the shallow boring program at Rayburn's Dome and processing of about half of the newly acquired Rayburn's cores; (2) redefinition of the shallow boring program at Vacherie; (3) completion of the geomorphic studies at Vacherie Dome concerned with stream preservation and dissection; and (4) continuation of the pollen studies at Vacherie and Rayburn's Domes.

ACTIVITIES DURING THE REPORTING PERIOD

All laboratory analyses of pollen samples from Vacherie and Rayburn's Domes were completed during the quarter, and a topical report entitled Palynological Studies -- Vacherie and Rayburn's Domes, North Louisiana Salt Dome Basin was submitted to DOE to be approved for publication.

Laboratory Analyses of Cored and Washed Samples

The final suite of borings was completed for Rayburn's Dome, and laboratory analyses of these returns are about 90 percent complete. All of the Rayburn's samples are being moved to a new location, being carefully catalogued with the assistance of QA personnel, and are being otherwise processed for final storage.

Summary Report on Rayburn's Quaternary Geology

Work is progressing on the preparation of the various maps, sections, and related figures that will accompany the report on Rayburn's Quaternary geology, and in analyzing and summarizing all data that have been developed on the Rayburn's site by the Quaternary Studies Group.

Grain-Shape and Grain-Surface Studies

These studies should be of value in determining whether the "anomalous" sands at Vacherie Dome and the boulder zone at Rayburn's Dome are of Quaternary age. Analyses of the data on the grain-shape and grain-surface studies were received during the quarter.

LSU Core-Hole Site Restoration

Plans and specifications for restoring the Rayburn's and Vacherie core-hole sites were received.

FUTURE ACTIVITIES

Restoration of the core-hole sites at Vacherie and Rayburn's domes is planned. Analyses of cored and washed samples made at Rayburn's during FY 80 will be completed. A topical report on the grain-shape and grain-surface studies at Vacherie and Rayburn's Domes will be prepared, as will a file report on carbon-oxygen ratios in the boulder zone at Rayburn's. Work on the Summary Report on Rayburn's Quaternary Geology will continue.

REFERENCES

Cohen, S., and S. C. Pieper, 1979. SPEAKEASY Manual: The SPEAKEASY III Reference Manual OS/VS Version, Speakeasy Computing Corp., Chicago, IL.

Martinez, J. D., M. B. Kumar, C. R. Kolb, and J. M. Coleman, 1981. "Catastrophic Drawdown Shapes Floor", Geotimes, March.

WBS 1.3.3

PROJECT: Louisiana Hydrology

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, District Office, Baton Rouge, Louisiana (G. N. Ryals)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The objective is to compile regional geohydrology maps for the northern Louisiana Salt Dome Basin and to conduct hydrologic field studies, data collection, and analyses near Vacherie and Rayburn's Salt Domes. A regional, multilayered ground-water flow model will be designed.

PROGRESS REPORTED PREVIOUSLY

Potentiometric surface maps of the Sparta and the Wilcox-Carrizo aquifers, a base-of-freshwater map of the northern Louisiana Salt Dome Basin and vicinity, and selected hydrologic data from the vicinity of Rayburn's and Vacherie Salt Domes were published.

ACTIVITIES DURING THE REPORTING PERIOD

During the past quarter, work objectives were to (1) maintain the ongoing ground- and surface-water data collection network, (2) analyze the geologic and hydrologic data from the area characterization test drilling activities, and (3) begin preparing a report to summarize the USGS regional study and data needs in north Louisiana.

Aquifer tests and water samples from the 16 test wells for area characterization were analyzed.

FUTURE ACTIVITIES

The next quarter's work will focus on analyzing the data from the area characterization test drilling program. Although the data are not sufficient for a detailed regional multilayered ground-water flow model, developmental work on a skeletal ground-water flow model will begin. A report will be prepared to summarize USGS regional study and data needs in north Louisiana.

WBS 1.3.3

PROJECT: Mississippi Hydrology

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, Water Resources Division (WRD), District Office, Jackson, MS (P.A. Dooley)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The objective is to describe the geohydrology of the Mississippi Salt Dome Basin and nearby selected domes with respect to the direction and rate of ground-water flow.

PROGRESS REPORTED PREVIOUSLY

This project began in July, 1977. A summary of activities during the preceding quarter is as follows:

1. Potentiometric heads in the Wilcox, Sparta, Cook Mountain, and Miocene aquifers around Richton and Cypress Creek Domes were calculated.
2. Ranges of hydraulic conductivity (K) were determined for each of these major aquifers.

ACTIVITIES DURING THE REPORTING PERIOD

The objectives have been to develop a conceptual model of ground-water movement near Richton and Cypress Creek Domes; determine local empirical relations between formation water resistivity and dissolved solids content; and calculate field formation resistivity factors (F_f) for the Wilcox, Sparta, Cook Mountain, and Miocene aquifers in southeastern Mississippi (Turcan, 1966).

A preliminary model to incorporate the observed potentiometric heads and water quality conditions in the Tertiary aquifers was developed.

Quality of water in the selected Tertiary aquifers can be estimated from induction logs using the F_f's and the local empirical relations that were established.

FUTURE ACTIVITIES

Preparation of a report summarizing the analysis of data collected during the area characterization phase of investigations in Mississippi will begin.

REFERENCE

Turcan, A. N., Jr., 1966. Calculation of Water Quality from Electric Logs--Theory and Practice, Water Resources Pamphlet No. 19, Louisiana Department of Conservation, Louisiana Geological Survey, Louisiana Department of Public Works, 23 pp.

WBS 1.3.3

PROJECT: Lake Superior Region Granitics

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (D. W. Powers)

ONWI PROJECT MANAGER: R. R. Nicks

OBJECTIVE

The objective of this program is to screen a previously identified granitic region in the Lake Superior district to identify areas which are favorable for further characterization. The screening program will use only existing data; no field investigations will be conducted during region-to-area screening. As part of this project, Sandia National Laboratories will form a Regional Advisory Group of geotechnical experts to provide consultation regarding the screening process. Sandia will interface with this group and will use regional expertise in conducting the screening process. The final objective is to provide a report which identifies areas (within the region) that are favorable for further characterization.

PROGRESS REPORTED PREVIOUSLY

This project began on 9 June, 1980. Case structures were activated, literature searches were initiated, and screening criteria were reviewed. No agencies within the region were contacted pending agreements between the Department of Energy and the states of the Lake Superior district. Literature searches and a criteria review were conducted. GEOREF, an on-line computer bibliography, was searched using key words. This has produced an extensive bibliography for use in the project that supplements a card file with references to the geotechnical literature of the Lake Superior district before 1960. More detailed screening criteria were drafted for some of the general criteria contained in NWTS-33(2). Literature was ordered from the Minnesota Geological Survey.

ACTIVITIES DURING THE REPORTING PERIOD

The literature search and review has been continued, principally for the State of Minnesota.

Potential failure scenarios for the Lake Superior region are being examined to determine which geotechnical criteria from NWTS-33(2) are most important. This activity produces values for screening criteria which are conditioned by the regional geology and indicates important objectives for the next level of characterization.

A survey of important geological and hydrological parameters for the Lake Superior region were accelerated to evaluate important repository failure scenarios. The development of these failure scenarios was initiated to provide screening values. The screening values will be the important action in the screening criteria.

FUTURE ACTIVITIES

Initial contacts will be made with potential members of the Regional Advisory Group.

Draft scenarios for screening values will be partially completed during the quarter. Review of the information from Minnesota will continue.

REFERENCE

Office of Nuclear Waste Isolation, 1980. NWTS Criteria for the Geological Disposal of Nuclear Wastes: Site-Qualification Criteria, NWTS-33(2), Battelle Memorial Institute, Columbus, OH.

WBS 1.3.3

PROJECT: Data Compilation and Map Publication--Lake Superior Region (Minnesota)

PRINCIPAL INVESTIGATOR: Minnesota Geological Survey, University of Minnesota (M. Walton)

ONWI PROJECT MANAGER: R. R. Nicks

OBJECTIVE

The objective of the Minnesota Geological Survey (MES) efforts is to update and publish geologic maps of the State of Minnesota and the Lake Superior Region, and to develop a comprehensive bibliography of significant literature on Minnesota geology. The information to be published will provide maps with statewide (Minnesota) coverage of bedrock geology, topography of the pre-Quaternary bedrock surface, simple Bouguer gravity, total intensity magnetic anomalies, bedrock outcrops, and Quaternary geology. The products of this effort will provide the fundamental information necessary to evaluate the Lake Superior Region as a whole, and areas within it, for nuclear waste repository siting.

PROGRESS REPORTED PREVIOUSLY

The program was initiated on 1 January, 1981. This is the first reporting period for the project.

ACTIVITIES DURING THE REPORTING PERIOD

Maps are being updated and drafted in final form for printing and publication, and a detailed search for literature on Minnesota geology is in progress.

FUTURE ACTIVITIES

Activities will continue until publication of the data, presently anticipated during the second quarter of FY 82.

WBS 1.3.5

PROJECT: Environmental Characterization

PRINCIPAL INVESTIGATORS: NUS Corporation
(J. DiNunno, W. Belter)--Salina and Permian;
Bechtel Group, Inc. (N. Norman)--Gulf Coast and
Paradox

ONWI PROJECT MANAGERS: NUS--D. J. Guzzetta;
BGI--R. B. McPherson, F. L. Moleski

OBJECTIVE

The objective is to conduct environmental studies at the regional, area, and location levels as a means of identifying environmental aspects of concern or interest in relation to the geologic formation of interest. The studies provide a means of identifying sites that may be potentially the most suitable for a repository as well as documenting the base data to be used in subsequent licensing documents such as Environmental Reports.

PROGRESS REPORTED PREVIOUSLY

The characterization tasks were begun on 7 July, 1977.

Publishing efforts continued on the Gulf Coast final regional and regional summary reports and the draft area environmental characterization reports. A meeting was held with Bechtel to initiate work on the Gulf Coast Site Characterization Plan. The final draft report of the transportation study that estimates doses to the population from nuclear waste shipments to salt domes was prepared by Bechtel.

Work continued on the regional summary report and the area environmental characterization report. An environmental evaluation of the area studies in the Paradox Basin was initiated by Bechtel.

The subregional summary and area recommendation report for the Permian Region was initiated by NUS. The Environmental Evaluation for planned drilling in the Permian Basin was reviewed.

ANL began regional environmental characterization in the Minnesota portion of the Lake Superior Region. Work in Michigan and Wisconsin will proceed after consultation with these states.

ACTIVITIES DURING THE REPORTING PERIOD

Gulf Coast Salt Dome Region

Two final reports related to the Gulf Coast were received from Bechtel: Regional Environmental Characterization Report for the Gulf Interior Region and Surrounding Territory (ONWI-67) and Summary Characterization and Recommendation of Study Areas for the Gulf Interior Region (ONWI-18).

A meeting was held at ONWI with Gulf Coast state representatives to discuss the Site Characterization Plan (SCP) schedule and state involvement. As a result of this meeting, Bechtel began the environmental sections of the SCP.

Assembly and testing of equipment for environmental field work was completed during the quarter. This equipment will be stored until location studies commence.

A public information meeting was held in Richton, Mississippi, on 24 February, 1981.

Paradox Basin

The final report, Regional Environmental Characterization Report for the Paradox Bedded Salt Region and Surrounding Territory (ONWI-68), was received from Bechtel. Two public draft reports, Summary Characterization and Recommendation of Study Areas for the Paradox Basin Study Region (ONWI-36) and Environmental Characterization Report for the Paradox Basin Study Region, Utah Study Areas (ONWI-144), were received from Bechtel and sent to libraries in Utah and Colorado.

The environmental evaluation of area studies in the Paradox Basin Study Region was completed and sent to DOE. Environmental assessment information was provided to the Bureau of Land Management in Utah for their use in evaluating permit applications to complete geologic area studies.

Bechtel prepared a report on water availability in Southeastern Utah for a repository and associated increased population. The report also evaluates ways to reduce water consumption at a repository, such as the use of runoff, domestic conservation, and wastewater recycling. Preliminary results of the transportation access study in Southeastern Utah were received from Bechtel.

Permian Region

Preparation of the subregional summary and area recommendation report for the Permian Basin continued. A working draft of the Permian geologic report prepared by Stone & Webster Engineering Corporation was sent to NUS to assist them in preparing the summary report.

WBS 1.3.5

PROJECT: Lake Superior Regional Environmental Characterization

PRINCIPAL INVESTIGATOR: Argonne National Laboratory (J. L. S. Saguinsin)

ONWI PROJECT MANAGER: N. J. Beskid

OBJECTIVE

The objective of this project is the environmental characterization of the Lake Superior Region, including the upper peninsula of Michigan and the states of Minnesota and Wisconsin. This is an initial step in an orderly process of identifying favorable locations for nuclear waste terminal storage sites.

The major elements of the project are (1) collection of relevant environmental data, (2) preparation of a Regional Characterization Report, and (3) preparation of a Summary Report with Recommendation for Area Studies. Preparation of each report will involve several cycles of ONWI (or public) review, comment, and appropriate revisions.

PROGRESS REPORTED PREVIOUSLY

Work on the project started on 2 December 1980. This is the first quarterly technical progress report.

ACTIVITIES DURING THE REPORTING PERIOD

The project team began work on the characterization of the Lake Superior Region, but activities have been limited to Minnesota. Data collection was performed using sources of information identified in the Region Survey Plan (dated January, 1980) and other, more up-to-date sources.

Data collection for Minnesota was essentially completed by the end of February, and the writing of a preliminary draft report began. A preliminary draft characterization report on Minnesota was completed.

FUTURE ACTIVITIES

A copy of the preliminary draft characterization report on Minnesota will be sent to ONWI after being reviewed in-house at ANL.

The project team will carefully review the Region Survey Plan and, in the light of their experience on Minnesota, will make suggested changes and improvements in the plan. These will be transmitted to ONWI.

WBS 1.3.5

PROJECT: Regional Environmental Characterization Studies--Southern Appalachian Region

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (J. R. Krummel and S. G. Hildebrand)

ONWI PROJECT MANAGER: N. J. Beskid

OBJECTIVE

The objective of this task is to characterize the environment of the Southern Piedmont region that includes a number of granitic formations which have geologic characteristics potentially suitable for permanent disposal of nuclear wastes. The region will be screened, using environmental criteria, in order to identify the most favorable areas for further study. This task supports the ONWI overall goal of providing a significant degree of assurance that high-level nuclear wastes can be isolated from the biosphere in a safe and environmentally acceptable manner.

PROGRESS REPORTED PREVIOUSLY

This project started 1 March, 1981. This is the first quarterly technical progress report.

ACTIVITIES REPORTED DURING THE REPORTING PERIOD

The locations and type of granite within the Southern Piedmont have been digitized and inputted to the computer for statistical analysis and mapping purposes. The USGS NASQAN (National Stream Quality Accounting Network) water quality data have been made compatible with the ORNL Geoecology Data Base for water quality analysis. The water quality analysis has begun on the major water basins in the study region and includes variables associated with sediment, nutrient, and toxic substances loadings. Important agricultural and forestry resources in the region have been located, and these resource areas are being overlaid on the granitic areas. The region has small amounts of cropland, but is productive in forestry and pasture land uses.

FUTURE ACTIVITIES

The regional characterization study will concentrate on the information in the Geoecology Data Base and data made available by the states. Work on the summary report that combines the regional environmental and geologic information will begin during the next quarter.

WBS 1.3.7

PROJECT: Study of Morro do Ferro

PRINCIPAL INVESTIGATOR: New York University Medical Center (M. Eisenbud)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective of this project is to study the natural transport of thorium and other elements from Morro do Ferro. The thorium deposit on the Morro do Ferro, a hill on the Pocos de Caldas plateau in Minas Gerais, Brazil, offers what may be a unique opportunity to improve understanding of the behavior of plutonium over geologic time. Thorium is an actinide with chemical properties similar to plutonium in the +4 state. The Morro do Ferro deposit is estimated to contain 12,000 MT of thorium, and the deposit is believed to be about 80 million years old.

PROGRESS REPORTED PREVIOUSLY

The project began on 1 October, 1979. In the first year of study, thorium mobilization was assessed by (1) measuring thorium concentration in the water and suspended solids of a stream draining the Morro do Ferro basin, and (2) by analysis of dated cores from alluvial deposits in the drainage basin. A flume has been constructed in the stream channel and has been equipped with a continuous flow recorder and composite water sampler. In the interim, an extensive grab sampling program has provided material to assess the hydrological transport of thorium. The mean total thorium concentration was 0.52 μg/ℓ, with a standard error of 0.14 μg/ℓ. To a first approximation, the estimated mobilization rate of the thorium deposit was 5.8 x 10^{-8} per year. The average life of the thorium deposit, assuming the present rate of mobilization, would thus be about 17 million years.

Gamma spectrometric analysis of core samples from the downstream swamp indicated that the average thorium concentration in a volume roughly 44,000 m^3 was 150 μg/g. The thorium accumulation in this swamp was estimated to be less than 10,000 kg.

An X-ray fluorescence (XRF) system has been developed to permit rapid analysis of soil and sediment samples. The procedure for low-level (< 1 μg ℓ$^{-1}$) thorium analysis has been developed that permits isotopic separation of ^{232}Th, ^{230}Th, and ^{228}Th.

ACTIVITIES DURING THE REPORTING PERIOD

Most of the activity centered on data collection and analysis and on improvement of laboratory analytical techniques.

Site Characterization

Most of this effort is ongoing in Brazil. Environmental monitoring of the local meteorology and stream hydrology is being performed on a continuous basis in the Morro do Ferro basin. The south stream water chemistry is being studied, but no results are as yet available. Core samples from the mountain have been received, and studies to identify the mineral form of Th in them are being undertaken.

Supporting Research

Radiochemical Analytical Technique. Due to the long time required in the radioanalytical procedure for thorium isotopic analysis, the entire process (consisting of more than 50 steps) was reviewed in detail. Two steps, the xylene wash and the second Aliquat-336 extraction, were eliminated. No further modification of the thorium isotopic analytical procedure is envisioned in the near future. The procedure is now being formalized and should be especially applicable to any soils and waters that possess the high rare earth concentrations such as those seen at the Morro do Ferro.

Uranium isotopic analysis has been developed nearly to the point of coupling with the thorium procedure. The procedure uses titanium trichloride to reduce U^{+6} to U^{+4} and chromium (II) chloride to hold uranium in the +4 state. In the reduced state, uranium is carried on barium sulfate followed by organic extraction similar to the thorium procedure. The process has been successful with uranium tracer solutions. Soil samples are now being attempted. A ^{232}U standard solution has been acquired and is undergoing further purification for use as a quality control check on U recovery.

XRF Spectrometry. XRF activities included (1) quantitative analyses of 72 solid samples taken from the Morro do Ferro, (2) optimization of source-target-detector geometry, (3) assessment of the current lower limits of detection (LLD) for thorium and uranium, (4) development of a procedure for estimating the concentration of seven additional elements, and (5) improvements upon the accuracy of the Rasberry-Heinrich (RH) matrix correction computer program.

A total of 56 swamp cores, 14 soil samples taken from locations near the main deposit, and two sediment samples were analyzed quantitatively for 11 elements. The thorium concentration range was from 10 to 300 μg/g for swamp core samples and 90 to 12,500 μg/g for soil samples. These thorium values have been verified by γ-spectrometry and are currently being verified by radiochemical reduction and α-spectrometry. Concentration versus depth profiles for iron, zirconium, barium, lanthanum, cerium, praseodymium, neodymium, samarium, lead, thorium, and uranium were plotted for each sampling transect in the swamp. The analyses of the 72 core samples have been stored as matrix arrays on the basis of sample type (e.g., core or soil), concentrations and counting errors, and depth. Statistical comparisons are currently being performed on these samples.

Due to the radioactive decay of the source, the source-target-detector geometry was reoptimized. The thickness of the collimator was reduced, and the signal-to-background ratio was increased. A target-to-source distance must remain the same because the scatter angle for the source photons must still be ∿ 180 degrees, allowing for minimization of spectral interference with thorium and uranium. A newly constructed sample holder is now adjustable so that the target can be moved vertically, keeping this original distance between source and target. The overall increase in the net counts-to-background ratio reduced the lower limit of detection for each element. For thorium and uranium, the LLD for a 1,000-second count time using a 40 mCi ^{57}Co source and Type I and Type II errors of 0.10 and 0.05, respectively, was 21 μg/g and 12 μg/g, respectively.

Seven additional elements were encountered during the routine analysis of the Morro do Ferro samples. In response to this, a procedure was developed for estimating molybdenum, niobium, europium, gadolinium, dysprosium, ytterbium, and hafnium, which were the observed elements. The estimation technique is valid upon the reasonable assumption that Nb and Mo have the same matrix effects as that of Zr, and similarly, Gd, Dy, Eu, Yb, and Hf as that of Sm. Thus, the current system permits quantitation of 11 elements and estimation of an additional 7 elemental concentrations.

To improve the RH matrix correction program, four additional multielement standards were prepared. Two of these standards had high cerium concentrations, 35,000 μg/g and 95,000 μg/g. These standards now allow quantitation of unknown Ce concentrations higher than 3 percent which have been encountered in soil samples from the main ore deposit. The other two standards had low concentrations of Th, U, and rare earths. Because of the large range of elemental concentrations and large elemental matrix effects encountered in samples from the Morro do Ferro, these RH standards help eliminate error in the RH matrix coefficients which are in turn due to errors in measurements of the X-ray intensities.

Geochemical Interpretation

Water Samples. Comparative data are now available between sampling sites located in the main drainage basin and all control locations. The data are presented in Table 1. The South Stream drains the main basin. The North Stream drains the north slope of the Morro do Ferro. The Opposite Ridge is a stream that drains the ridge opposite the Morro do Ferro and is a tributary to the South Stream. The Off Plateau sampling site is a surface stream located in the town of São João da Boa Vista which is off the Pocos de Caldas plateau to the southwest. The Opposite Ridge sampling site is considered an immediate control site, since it is located in the same drainage basin as the South Stream sampling site. The Off Plateau site serves as a representative of the general region away from the anomalous Pocos de Caldas plateau.

In general, the filtrate data conform to expectation. The South Stream is about a factor of 20 higher than the Off Plateau site. Both the North Stream and Opposite Ridge sites are higher by a factor of two than the Off Plateau location. The Opposite Ridge mean thorium filtrate concentration appears high relative to the South and North Streams, but only a few samples have been analyzed and it may just represent sampling error. In the filterable fraction, both the South Stream and the Opposite Ridge sites yield high mean concentrations of thorium by weight. This suggests that particles of very high Th concentration may be caught in the filter and possibly bias the concentration value, since little difference is noted in the sediment loads between these sites. The Off Plateau stream is an order of magnitude higher in sediment load than that of the on-plateau sites, confirming the visual observation of high turbidity.

Table 1. Mean Surface Water Thorium Concentrations.

Location	N	Filtrate(a) μg/ℓ	Filterable(b) μg/ℓ	μg/g(c)	Total Th, μg/ℓ
South Stream	(28)	0.26	0.24	150	0.50
North Stream	(1)	0.02	0.29	--	0.31
Opposite Ridge	(2)	0.02	0.35	165	0.37
Off Plateau	(3)	0.01	0.30	25	0.31

(a) The samples volumes varied from 10 to 20 ℓ.

(b) 0.45 μm membrane filtration.

(c) μg thorium per gram of suspended solids.

Soil and Core Samples. Table 2 lists the soil and core concentration ranges found for the 11 elements through XRF analysis. The data are segregated into three regions including the Ore Deposit, the General Basin, and Off Plateau areas. With the exception of U and possibly Zr and Ba, all other elements show elevated concentrations of the ore body as opposed to the other two regions. With the exception of Zr and Ba and possibly Fe, the general Morro do Ferro basin shows elevated concentrations of all the rest of the elements when compared to the Off Plateau samples. The data indicate a general ubiquity for Zr and Ba across all three regions. Uranium appears fairly uniform and elevated in concentration in the Ore Deposit and General Basin regions when compared to the Off Plateau samples.

Table 2. Elemental Concentration Ranges, μg/g.

Element	Ore Deposit	General Basin(a)	Off Plateau
Thorium	1,000 to > 10,000	50 to 300	10 to 40(b)
Uranium	40 to 60(b)	10 to 100	< 10(b)
Lanthanum	500 to 10,000(b)	200 to 1,300	15 to 200(b)
Cerium	5,000 to 30,000(b)	500 to 1,500	40 to 300(b)
Praseodymium	100 to 2,000(b)	40 to 150	< 30(b)
Neodymium	300 to 10,000(b)	100 to 500	< 90(b)
Promethium	100 to 2,000(b)	30 to 150	< 30(b)
Samarium	30 to 500(b)	10 to 50	< 10(b)
Iron	300,000 to 360,000(b)	10,000 to 100,000	5,000 to 60,000(b)
Zirconium	1,700 to 4,000(b)	800 to 2,500	500 to 1,800(b)
Barium	200 to 1,200(b)	50 to 500	20 to 800(b)

(a) Includes depth-averaged core concentration values.

(b) Includes sample only.

Qualitative inspection of the elemental distributions found in the swamp cores indicates the rare earth elements Ce, Pr, Nd, Pm, including La, follow each other faithfully with depth. Thorium appears to be associated with these elements, while the trend is less clear for uranium. Correlation analysis and scattergram plots are now being created to assess quantitative relationships.

Radioactive Equilibrium Studies. Sixteen soils and core samples have been analyzed radiochemically for thorium isotopic equilibrium between the ^{232}Th parent and the ^{228}Th great granddaughter. The possibility of disequilibrium exists since ^{228}Ra is an intervening daughter and is environmentally more mobile. Within statistical counting error (within 10 to 20 percent) the isotopic ratio is unity, indicating equilibrium. This result lends strong support for the rapid analysis of thorium via quantitation of the 2.62 MeV gamma energy from ^{208}Tl. This assumes negligible thorium escape previous to reaching the ^{208}Tl daughter in the ^{232}Th decay chain.

FUTURE ACTIVITIES

Third quarter activities will include (1) validation of the XRF technique for soil samples taken in the U.S. to assess its general applicability, (2) further development of the uranium isotopic radioanalytical procedure, (3) further data analysis of the swamp cores, and (4) preliminary analysis of meteorological and surface hydrologic field data.

WBS 1.3.7

PROJECT: Hydrology of Nearly Impermeable Rock

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (T. Doe and J. Long)

ONWI PROJECT MANAGER: M. R. Wigley

WELL TEST

OBJECTIVE

The objective of the first task is to develop improved well test techniques for low-permeability rocks by (1) evaluating the constant head (pressure) injection test, and (2) developing transient flow-rate solutions for a variety of flow-path geometries. Specifically, solutions and field methods will be developed for determining fracture apertures, the areal extent of fractures, and the nature of the hydraulic interconnection of fractures (fracture boundary conditions). Such a tool can be used to generate probability density parameters of functions for fracture geometry, which in turn can be used as input to stochastic flow models and hydrologic transport risk analyses.

PROGRESS REPORTED PREVIOUSLY

Analytical solutions for constant head, transient flow-rate injection tests on single fractures were prepared for a variety of open and closed boundary conditions. In addition, solutions were prepared which include fracture deformation using coupled stress-flow numerical codes, showing that fracture deformation substantially alters the shape of the transient flow-rate curve one would expect in well testing. This alteration affects the interpretation of permeability and storativity.

ACTIVITIES DURING THE REPORTING PERIOD

The activities have focused on preparing equipment to test single fractures using the transient flow-rate constant head technique. A downhole, pneumatically operated valve, which allows instantaneous application of the constant head to the test zone, has been designed and fabricated. In addition, a low-flow-rate positive displacement flow meter has been designed and fabricated. It consists of a plunger in a half-inch cylinder. Compressed air or water from a constant pressure source drives the plunger and supplies the constant head to the test zone in the well. The displacement of the plunger is monitored using a 20-in. displacement transducer which can read the motion of the plunger to within 0.001 in.

The software for the minicomputer data acquisition system is now operating. The computer collects the flow data at rates of up to one reading per second. The displacements of the displacement transducer are converted to injection volumes, and the flow rates are calculated based on the elapsed time between readings. The data are displayed on a CRT, typed on a printer, and stored on disk for future data analysis, and a choice of semilog or log-log graphs of the flow rate versus time is displayed on the CRT. The CRT graphics are continuously updated during the operation of the test and provide the test operator with immediate feedback on the progress of the test.

FUTURE ACTIVITIES

During April, 1981, the field test system will be taken to the field for a series of constant head injection tests on single fractures in a 100-ft-deep well. Tests will be run at a variety of injection pressures to determine the role of fracture deformation in test behavior. Analysis of the test data will be completed, along with modeling work on transient flow in partially open fractures. The test data will be analyzed to determine if transient flow techniques can be used to determine the areal extent of fractures.

PERMEABILITY STUDIES

OBJECTIVE

The objectives are to determine (1) when a fractured rock system may be treated as an equivalent homogeneous, anisotropic porous medium, and (2) what values of equivalent porous media properties apply to such systems. Objective (1) involves building numerical models of fracture systems and subjecting these systems to simulated flow tests. Response to these flow tests can then be compared to the theoretical response of a porous medium. When the response of the fractured system is comparable to the theoretical response, the system can be considered to have an equivalent porous media permeability. Once fracture systems are found which have equivalent media permeabilities, fracture systems will be described in statistical terms.

The object of this phase will be to find both the effect of variation of the statistical parameters and the variation in permeability between fracture systems that are different realizations of the same statistical population.

PROGRESS REPORTED PREVIOUSLY

This project started in January, 1980. In FY 80 a literature survey was completed in three areas: the permeability of fractured rock systems; the theory of homogeneous, anisotropic media; and the statistics of fracture geometry. A numerical fracture system model was adopted and coupled to a fluid flow program for numerical permeability testing. The model was validated for extensive or infinite fractures, and then a random example of nonextensive fractures was studied. Criteria for behavior as an equivalent porous medium were developed. The capability of plotting isopotentials was added to the numerical program. A literature survey was conducted to find methods for linear regression of the permeability data to an ellipse.

ACTIVITIES DURING THE REPORTING PERIOD

A parameter study was performed in order to provide a framework for further sensitivity analyses. The parameter study showed how changes in system parameters individually affect the hydraulic performance of fracture systems. Results were compared with and confirmed intuitive expectations for behavior. In these studies density, aperture distribution, orientation distribution, and mesh size were varied. Increases in fracture density, uniformity of aperture distribution, and nonuniformity of orientation distribution all caused the fracture systems to behave more like porous media. Increasing the mesh size showed that, although small volume may behave hydraulically like a porous medium, it is not necessarily representative of the entire rock mass.

FUTURE ACTIVITIES

The finite-element fracture flow program will be fitted with a new solver so that larger problems can be analyzed. Sensitivity analysis will be continued. A linear regression model for a best fit permeability ellipse will also be pursued.

WBS 1.3.7

PROJECT: Behavior of Natural Repositories

PRINCIPAL INVESTIGATOR: Los Alamos Scientific Laboratory (D. B. Curtis)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objectives of this study are (1) to develop an understanding of migration and retention of fission products and other radionuclides in natural repositories such as Oklo and rich uranium ore bodies, and (2) to relate their behavior to the performance of a mined geologic repository.

PROGRESS REPORTED PREVIOUSLY

The U.S. participation in the international investigation of the Oklo natural fission reactor phenomenon began in FY 75. The first formal report of progress was issued in November, 1976.

The Oklo phenomenon refers to the occurrence of self-sustaining fission chain reactions about 2 x 10^9 years ago in a series of very rich uranium ore pockets located in Gabon, Africa. Criticality lasted several hundred thousand years, and approximately 10 tons of uranium were fissioned. Many fission products were retained at the sites where they were generated. Other products from uranium decay or fission have been shown to be missing in whole or in part from the fossil reactor cores.

Previous reports discussed the redistribution of ^{99}Tc relative to ruthenium and ruthenium and lead relative to uranium. Transport paths were identified in the ores and in the rocks which confine the ores. Limits were placed on the times when the element redistributions occurred.

To extend the work to physical, chemical, and geologic environments that differ from those found at Oklo, samples from a rich uranium ore body at Key Lake in Saskatchewan have been studied. The rich uranium ores at Key Lake did not attain nuclear criticality. Therefore, these studies have been confined to the fractionation and redistribution of lead produced by radioactive decay of uranium and thorium: A massive redistribution of uranium, thorium, and lead occurred in metamorphic rocks containing the ores and in the underlying Athabasca sandstone. This element redistribution was contemporaneous with the deposition of the overlying sandstone 1.3 x 10^9 years ago. Relative excesses and deficiencies of radiogenic lead identify extensive mobilization and redistribution of elements in the ores, in the metamorphic basement, and in the overlying sandstone.

ACTIVITIES DURING THE REPORTING PERIOD

Characterization of Oklo Reactor Zone 9

Eight samples from the reactor zone were analyzed for isotopic abundances of molybdenum, ruthenium, cerium, neodymium, uranium, and lead. However, only the data for neodymium have been used to reconstruct the operating parameters of the reactor.

Fissiogenic Elements in Rocks Peripheral to Reactor Zone 9

The identification of small amounts of ^{235}U-depleted uranium in rocks external to the reactor zones and beyond the range of neutrons produced in reactor zone 9 indicates that uranium has been removed from the reactor zone, transported over distances of meters and tens of meters, respectively, and redeposited in the rocks where it was found.

Retention and Transport of Alkali and Alkaline Earth Elements at Oklo

Barium isotope abundances are being measured in samples from reactor zone 9 of the Oklo mine and in rocks peripheral to this zone to obtain data about the migration and retention of fissiogenic cesium and barium in the Oklo natural repository. Four of the seven stable isotopes of barium can be formed from uranium fission. The cesium precursors of three barium isotopes (^{135}Ba, ^{137}Ba, and ^{138}Ba) have vastly different half-lives: 3 x 10^6 years, 30 years, and 32 minutes, respectively. The times of fractionation of cesium and barium relative to the time of formation of the fission products should become apparent through knowledge of the precursor half-lives and measurement of the barium isotopic abundances.

Preparation and Characterization of Reduced Aqueous Solutions

The controlled inert atmosphere glove box and purification system are completely installed and tested. Several experiments for producing and measuring low-oxygen-fugacity water systems and negative Eh water systems are being installed inside the glove box.

Important Findings in the Uranium Immobilization Study

Several important conclusions have been reached. The importance of redox conditions for the fixation of uranium has been confirmed. Although other factors, such as pH and anion concentration, affect uranium solubility, the redox state of the solution seems to be the most important variable in the natural environment.

Not all ground waters are in equilibrium with the rocks through which they flow, although there is a general trend toward more reducing conditions as one moves down an aquifer away from the recharge area. Bacterial activity may be important as a reduction mechanism. Of the several redox zones that can be detected in ground-water systems, uranium precipitation in natural low-temperature systems is particularly associated with the sulfate reduction zone. This observation is in good agreement with current thermodynamic data, which predict uranium solubilities of less than 1 ppb at near neutral pH and reducing conditions under which sulfide becomes dominant over sulfate.

SUMMARY

1.4 REPOSITORY

The scope of the Repository Task covers the development of design specifications, preparation of a repository design data base, development of instrumentation and equipment, design and development of repository designs and repository seals, and performance evaluation of the repository within the total nuclear waste isolation system. The prime objective of the repository task is to develop suitable repository designs, including required instrumentation and equipment. Progress in various R&D areas is summarized below:

Salt Data Base

The post-test evaluation of the Site A and Site B heater tests at Avery Island was initiated in March. Data gathering activities related to Sites A and B heater tests were accelerated during the power reductions. Also, plans were made to terminate the heating and moisture collection at the Site NB (natural brine) brine movement experiment; a brine inflow model was developed; the two accelerated borehole closure experiments were discontinued; and the extended permeability measurement experiments were concluded.

The studies of transient creep in rock salt involved a variety of activities this quarter. These activities included (1) application of the one- and two-mechanism fits to the experimental data on warm-pressed, synthetic specimens; (2) comparison of the experimental data with those of other workers; (3) presentation of the subgrain size versus differential stress data, including those for stress-relaxation tests, and comparison of these data with other data for experimentally deformed natural rock salt; (4) deformation of synthetic specimens at 25 C and confining pressures of 0, 20, and 100 MPa; and (5) structural characterization of rock salt specimens from Avery Island that will be experimentally deformed in the new large-specimen apparatus.

The major thrust of the radiation damage to rock studies is to determine the effects of irradiation over a range of temperatures in various host rocks in order to predict long-term radiation effects. The resulting data will be available to help evaluate candidate host rocks. Currently, radiation damage measurements have been made on a large variety of natural rock salt samples to determine if the radiation damage characteristics of natural rock salt (1) are dependent on the geological origin of the salt or (2) vary among horizons at the same site. Thermoluminescence (TL) measurements of natural and synthetic rock salt will provide information on the different electron and hole traps that occur in solids. Often these traps are defects, and if this is so, TL measurements can be used to study the introduction of defects during irradiation and their removal during heating.

Granite Data Base

The main activity this quarter in defining expected repository environments in granite was to identify and characterize the major granitic formations in the United States. Certain geologic characteristics, which include factors of depth and lateral extent, tectonic stability, seismicity and faulting, and natural resources, were taken into account.

The main effort of the heated block test in granitic gneiss at CSM this quarter was startup of the nine borehole heaters. The preliminary results indicate that elevated temperature flow tests should be an integral part of repository site characterization.

Measurements of rock-mass modulus of deformation (Er) at the CSM experimental mine using the NX-CSM cell were completed during this quarter. In addition, significant progress was made in developing a computer program to analyze the fracture data from core logging, in-hole petroscope logging, and structural mapping. This program should produce any statistical description desired for fracture quantity data comparison.

Final documentation of the field results obtained from the Swedish American Cooperative project continued. The data base resulting from fracture mapping and core logging in the full-scale heater experiment drift is available as a computer-based listing of individual fractures. Compilation of the records of ground water infiltrating into heater and instrumentation boreholes during the operation of the three heater experiments is also complete. Computer-based calibrations of thermocouples used in the Stripa heater experiments have been plotted as differences with respect to the NBS standard calibration, which was used in reducing the field data, and extensometer sensor performance and related data have been compiled.

Two major activities took place this quarter on the Stripa data analysis program: (1) detailed examination of selected temperature data in relation to fractures, and (2) finite-element modeling to assess the possible influence of the overall Stripa mine excavations on the far-field in situ stress measurements in SBH-4, a deep hole drilled from the surface.

The materials properties testing program involved several tasks this quarter. The major effort was directed at installing the electric servocontrol system for automatic test machine control. Recalibration of various test machine components was also carried out. Another task involved testing of an improved sample pocketing and loading piston assembly. Stripa in situ stress measurement activities consisted of completion of the data analysis of the stress measurements conducted in SBH-4 during the summer of 1980 and preparation for the stress measurements to be performed underground at Stripa during the summer of 1981.

The international Stripa testing program continued with drilling of the vertical borehole (V1) down to about 506 m and start of drilling the horizontal borehole (N1) to about 100 m. The Buffer Mass Test also showed progress. Heater hole drilling, manufacturing of compacted samples, and production of the comprehensive documents for ordering bulwark steel structure units, rock anchoring, etc., took place.

The objectives of the fractured rock studies program are to develop, operate, and maintain a facility for testing ultra-large specimens of rock, and currently, to investigate the hydraulic properties of fractures as they pertain to fluid transport through the rock mass surrounding underground openings. The

Charcoal Black Granite specimen, reduced to 0.764 m in diameter and 1.52 m in height, was received at LBL. A series of falling head radial flow tests was conducted on the main fracture to get an idea of the conductivity of the fracture, in order to choose proper instrumentation to measure the flow rate during the subsequent steady-state radial flow tests.

The development of the thermo-mechanical-hydrological (TMH) fractured rock code ROCMAS continued, and preparation of the review paper on the status of modeling was completed.

Repository Sealing

The Bell Canyon Test Summary Report, which discusses an in situ evaluation of the ability of a cement grout plug to seal boreholes, is complete and has been reviewed by Sandia and ONWI. This report gives a general overview of the test, including test technique, analysis, the results obtained, and the conclusions drawn.

This quarter's work of the seal materials performance limits and longevity program focused on completing examinations of ERDA-10 grouts; examining five laboratory grouts aged 4 years and 1-year-old Bell Canyon Test specimens; continuing dynamic tests and compressive strength tests of those grouts; collecting and testing Class H high sulfate-resistant cements; and analyzing data through 90 days for grouts made to optimize BCT-1FF.

The objective of the seal materials selection and longevity program is to find materials with properties appropriate for repository sealing. Experiments and testing continued on cement-based materials, clay and clay composites, and zeolites to determine their feasibility for performing as seals in repository environments.

Laboratory experiments were continued to obtain experimental data on the wellbore damage zone caused by full-scale drilling operations. The plug flow test was successfully completed, and laboratory permeability measurements on anhydrite have continued.

Equipment and Instrumentation

The equipment reliability, availability, and maintainability (RAM) program has been completed. The final report, which presents a summary of the work performed and a rationale for developing the style and content of the RAM Guidebook, was received.

The final design of the major components of the nuclear quadrupole resonance spectrometer has been completed, and a high-power transmitter output component has been assembled.

Development of techniques to transmit, to the surface, sensor data collected within, or adjacent to, a subsurface nuclear waste repository continued. Data transmission system concepts were evaluated, and transmission system operational characteristics were developed.

A stress and displacement measurement technique program was started this quarter. The activities this quarter were concerned with completing a literature search and preparing a development plan to improve stress and displacement instrumentation based upon the results of the literature search.

WBS 1.4.1

PROJECT: ONWI Support Program: Program Coordination and Special Problems

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (A. L. Lotts)

ONWI PROJECT MANAGER: C. E. Raines

GENERAL ACTIVITIES

OBJECTIVE

The objective is to allow continuity in program planning and direction and to allow new or short-term project. to be undertaken.

PROGRESS REPORTED PREVIOUSLY

Work which has been previously undertaken and reported includes Sensitivity Analysis and Thermal Analysis, Preparation of a Licensing Topical Report on Brine Migration, and writing of a report on Materials Considerations Relative to Multibarrier Waste Isolation.

ACTIVITIES DURING THE REPORTING PERIOD

Work has continued on the thermal analysis project, and a new effort on analysis of salt core samples has been initiated at ONWI's request. Twelve salt core samples from the Asse Mine (FRG) and one salt core sample from the Richton Dome in the U.S. were received and are to undergo various analyses relating to water behavior.

The technical report, Material Considerations Relative to Multibarrier Waste Isolation, was submitted to ONWI and DOE for review.

FUTURE ACTIVITIES

During the next quarter, work will continue on the salt core analysis, and the report on materials considerations will be issued. New projects will be initiated as required and needed in coordination with ONWI personnel.

HEAT TRANSFER STUDIES

OBJECTIVE

The thermal analysis work is currently composed of two parts, one involving uncertainty assessment of waste repositories and the other involving documentation of thermal calculations for the Avery Island experiments.

PROGRESS REPORTED PREVIOUSLY

The subtask involving uncertainty analysis was begun in the second quarter of FY 80. A report entitled A Statistical Sensitivity Analysis of a Simple Nuclear Waste Repository Model was published. Work was begun on a second report of similar nature for granite repositories.

ACTIVITIES DURING THE REPORTING PERIOD

The draft report on a granite repository was revised, and a report entitled Sensitivity and Uncertainty Analysis of a Simple Near Field Granite Nuclear Waste Repository was published.

A report entitled Thermal Analysis Supporting the Design of the Avery Island Dome Salt In-Situ Experiments has been prepared.

FUTURE ACTIVITIES

The thermal analysis and the Avery Island thermal calculations will be published during the quarter.

The work on uncertainty analysis has been terminated.

EXPECTED REPOSITORY ENVIRONMENTS

OBJECTIVE

The objective is to identify the expected environments for nuclear waste and spent fuel repositories in bedded and domal salt. The environments or effects include temperature distributions and histories, brine flows, brine chemistry, and pressure.

PROGRESS REPORTED PREVIOUSLY

The report on commercial high-level waste (CHLW) and spent fuel, Environments in High-Level Nuclear Waste and Spent Fuel Repositories in Salt, was issued.

An analogous report for defense high-level waste (DHLW) was completed and a draft submitted to the Reference Repository Conditions Interface Working Group (RRC-IWG) for review.

ACTIVITIES DURING THE REPORTING PERIOD

The draft report on DHLW was revised in accordance with the comments received and published in March, 1981, as Expected Environments for a Defense High Level Waste Repository in Salt. The environments for DHLW are relatively benign because of the relatively low heat loading per package.

FUTURE ACTIVITIES

The following work was initiated at the end of the quarter and will comprise the main effort in the next quarter.

1. Determine sensitivity of near-field thermal environments in salt to advanced waste package design.
   a. Define idealized advanced waste package based upon ongoing ONWI work.
   b. Calculate waste center line (CHLW) or center pin spent fuel temperatures for appropriate variation in design parameters.
2. Determine dependence of salt thermal environments on realistic canister loadings and emplacement scenarios.
   a. Define source terms based upon realistic waste projections and emplacement schedules.
   b. Calculate near-field temperatures for canisters containing backlogged waste and later when the backlog has been worked off.
   c. Calculate far-field temperatures based upon a realistic loading scenario.
3. Compare thermal environments for several media based upon a common design basis.
   a. Determine appropriate design based upon RRC-IWG analyses to date.
   b. Calculate near-field rock thermal environments for selected areal loadings.

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WBS 1.4.1

PROJECT: Expected Repository Environments in Granite (ERE-G)

PRINCIPAL INVESTIGATOR: RE/SPEC, Inc. (J.D. Osnes)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this study is to establish the expected repository environments in a generic granitic repository containing commercial high-level waste, defense high-level waste, or spent fuel. The expected repository environments will be described in terms of transient temperature fields, deformations, resultant stress states and regions of stress failure, and perturbations to ground-water flow. In addition to these states or environments, consideration will be given to describing chemical and nuclear radiation environments and vapor pressures in the waste package drillholes and in the disposal rooms.

This work supports and addresses particular problems relative to the Rock Mechanics Program of the NWTS program. In particular, the ERE-G study provides technical bases for reports authored by the Reference Repository Conditions Interface Working Group (RRC-IWG), an ad hoc IWG established by the Isolation Interface Control Board.

PROGRESS REPORTED PREVIOUSLY

The ERE-G study was initiated on 1 October 1979. A draft of Interim Reference Repository Conditions for Commercial and Defense High-Level Nuclear Waste and Spent Fuel Repositories in Granite was completed in support of the RRC-IWG.

ACTIVITIES DURING THE REPORTING PERIOD

To predict the mechanical environments expected in reference repositories in granite, the mechanical properties and characteristics for the granite rock mass must be determined.

During this quarter, geologic and tectonic maps were consulted to identify major granitic formations in the United States. These formations were further studied to determine the suitability of granite as a repository medium taking into account certain geologic characteristics. These include factors of depth and lateral extent, tectonic stability, seismicity and faulting, and natural resources.

FUTURE ACTIVITIES

The literature will be reviewed to obtain data on the mechanical properties of granitic rock. Values or ranges of the mechanical properties will be chosen based on the available literature. Also, typical granitic rock mass properties such as joint frequency, orientation, and in situ stress state will be determined based on the structure and tectonics of the granite in these regions. Thermomechanical modeling based on these rock and rock mass properties will then be undertaken.

WBS 1.4.2

PROJECT: Experiment Development to Support Field Testing

PRINCIPAL INVESTIGATORS: Westinghouse Advanced Energy Systems Division (P. P. Zemanick, G. R. Kilp, and F. F. Klein) and D'Appolonia (L. Jarolimek)

ONWI PROJECT MANAGER: M. W. Anthony

OBJECTIVE

The principal objective is to develop test plans and hardware for future field tests to study (1) the phenomenon of brine migration in salt under simulated nuclear waste repository conditions, (2) waste-rock interactions under conditions simulating long-term barrier and waste degradation, and (3) the performance of engineered barriers under geological conditions.

PROGRESS REPORTED PREVIOUSLY

Work on this project began in December, 1979, with effort directed toward two tasks: Brine Migration and Waste-Rock Interaction. Effort in two other tasks has recently been initiated: waste package materials testing as add-ons to the Asse brine migration and technical assistance.

Brine Migration

A revised draft of the Brine Migration Test Plan at Asse, FRG, was issued that defined a plan consisting of four individual test sites in two different salt strata in the Asse mine, including tests with and without radiation sources. The tests would have a maximum salt temperature of 210 C. Basic agreement on this plan was obtained with the FRG, and a test site was identified.

Waste-Rock Interaction

Semiformal peer reviews of the preliminary test concepts for waste-rock interaction testing at the Asse mine resulted in the identification of technical concerns with the objectives of the program. Consequently, work on the existing draft Test Plan was largely suspended while systematic reviews were made of prior, current, and planned field test and laboratory programs. The objective of this effort was to develop a sound basis for further waste-rock interaction field test concept planning, responsive to the technical concerns raised during the peer review process.

Technical Assistance

In November, Westinghouse (with D'Appolonia as subcontractor) initiated development of a field test program for the Salt Test Facility (STF). A draft list of tests was issued and modified in several iterations based on comments from ONWI and other project participants. In mid-December, a preliminary set of facility requirements, based on the support needs for the final test list, was provided to Stearns-Roger to guide facility design. Two reports were begun. First, a technical bases document was initiated to describe the current most pressing issues regarding salt repositories and how the STF test program would serve to resolve the issues. Secondly, a test conceptual design document was initiated which was intended to provide details at the conceptual design level for ONWI-approved tests.

ACTIVITIES DURING THE REPORTING PERIOD

Brine Migration

Investigations of the planned test site in the Asse mine have begun with obtaining a core sample from the site. Preliminary evaluation of this sample has yielded a total water content of the U-type salt (transitional) from about 0.2 to 0.5 weight percent and of the S-type salt (pure) from about 0.01 to 0.06 weight percent. These are, respectively, higher and lower than expected.

FRG has reviewed the Revised Test Plan and has generally agreed with the approach outlined therein. Also, agreement has been reached on a number of other interface details.

Other reviewers of the Test Plan have questioned the applicability of the data obtained from Asse salt to U.S. disposal programs, and a decision was reached to conduct a major brine migration field test.

Work is continuing to complete the preliminary design of the test equipment. Development tests are beginning to assure that certain components will function in the test environment, particularly the seal, porous media, and instrumentation. Preliminary results indicate that both alumina and graphite beads will have sufficient strength to support the salt. Also, testing was conducted assuring that the high electrical noise environment associated with SCR (silicon controlled rectifier) power supplies for the heaters will not interfere with instrument indications. The design of the seal between the test assembly and the salt borehole wall has been revised to give a higher assurance of producing a leak-free seal. Work has been initiated on the final version of the test plan to be issued in the next quarter.

Waste-Rock Interaction

The effort applied to this task was limited during the report period, pending further determinations of requirements. Effort was redirected to writing a short summary report on the status of waste-rock testing, in both the laboratory and the field, and on documentation of the use and need for such tests.

Waste Package Materials

As the brine migration test plans have firmed up and as the waste package concept evaluation in other DOE- and ONWI-sponsored programs has progressed, interest in field testing of candidate waste package materials has increased. In particular, interest in using the brine migration test modules for piggyback materials testing has arisen. Consequently, a small effort was approved under this task to study the possibilities of conducting limited materials testing using the basic Asse mine brine migration test hardware. Any such tests must be planned such that the brine migration test objectives would not be compromised. This work, begun late in the quarter, has progressed only to evaluating types of materials and possible locations of tests (i.e., around heaters, attached to apparatus walls, etc.) with respect to the brine migration test design concept.

Technical Assistance

The planned contents for the Salt Test Facility Technical Bases Document were presented to ONWI and to all STF planning project participants. Individual test planning progressed to form a basis for an updated set of facility requirements for use in facility design. First drafts of the Technical Bases Document and the Test Conceptual Design Document were modified to incorporate technical comments from ONWI and were resubmitted.

FUTURE ACTIVITIES

Brine Migration

The Final Test Plan will be issued in the next report period as the design proceeds into the final design phase. Development testing will continue to assure proper test articles performance. A meeting will be held in June in the FRG to review the test plans.

Waste-Rock Interaction

The status report of waste-rock interaction testing in salt will be completed. The thermomechanical analysis of borehole behavior will be completed and documented in this report.

Waste Package Materials

A list and description of a group of tests suitable for integration with the brine migration test plan is to be developed. These test concepts will be issued as an appendix in the Final Test Plan for the brine migration test to be issued during the next report period.

Technical Assistance

The only outstanding activities in support of the STF test planning are assistance to ONWI in assembling a Records Turnover Package and possible facility design interface support.

WBS 1.4.2

PROJECT: ONWI Support Program: Thermal Property Measurements

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (J. G. Moore and M. T. Morgan)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this program is to obtain accurate thermal data to be used in thermal analysis of possible repository sites. Methods and procedures will be established for making thermal property measurements, and data will be obtained on selected specimens of cores from possible repository sites and standard natural materials.

PROGRESS REPORTED PREVIOUSLY

The program began in 1977. The ORNL thermal conductivity measurements of rock salt and other rocks and more recent measurements on Cypress Creek rock salt and caprock were significantly different from results obtained by the Energy Materials Testing Laboratory (EMTL) of Fiber Materials, Inc. Approximately half of the difference in the results could later be attributed to a difference in the values used for the Pyroceram 9606 reference material. EMTL used values derived from thermal diffusivity measurements, while ORNL used values from the NBS data series which were obtained by steady-state radial heat flow measurements.

Efforts to develop means of measuring the thermal conductivity of friable materials resulted in the development of a thermal conductivity cell which was tested with glass fragments. Many coatings and films were tested for improving the thermal contact in thermal conductivity measurements. Metal foils and graphite cloth proved to be ineffective at low pressures. The metals tested did not include indium foil, which may be applicable but is too expensive for routine use.

ACTIVITIES DURING THE REPORTING PERIOD

Six diffusivity measurements on Pyroceram 9606 from three sources by EMTL were received. These results, averaged with those of Rudkin (1963) and Gibby (1968), give the thermal diffusivity (cm^2/sec) over the range of 293 K to 673 K according to the equation,

$$\alpha = 0.007262 \exp(271.0/T),$$

where T is the temperature in degrees K. The maximum standard deviation for the eight sets of measurements was 4.36×10^{-4} cm^2/sec, and the maximum difference was <7 percent.

Thermal conductivities (W/mK) for the Pyroceram 9606 derived from the averages of the thermal diffusivities may be described by the expression,

$$\lambda = 2.676 \exp(88.00/T) \text{ (range = 293 - 573 K)}.$$

Thermal conductivities for Pyroceram 9606 obtained by radial heat flow measurements (Powell et al, 1966) follow the relation,

$$\lambda = 2.762 \exp(110.5/T) \text{ (range = 293 - 573 K)}.$$

The differences in the thermal conductivities obtained by the two methods range from 7 percent at 573 K to 10 percent at 293 K.

The thermal conductivities on an exchanged Pyroceram reference specimen between ORNL and EMTL differed by 19 percent at 573 K to 23 percent at 293 K. Approximately half of this difference can be attributed to the use of the different values for the reference meters. The remaining difference is due to experimental and instrumental causes. These differences are approximately the same as those in the thermal conductivity measurements obtained by ORNL and EMTL on Cypress Creek Salt.

The good agreement in most of the diffusivity measurements for Pyroceram 9606 indicates that these data should be accepted tentatively in place of the NBS data. Further evidence is needed, however, to determine whether there is some biased difference in measurements made by the pulsed laser and those made by steady-state heat flow measurements. Other references for the comparative method are being sought, and plans are in progress for changing the ORNL Dynatech instrument to make absolute steady-state measurements.

Additional coating materials for decreasing thermal conductivity at interface contacts were tested. Water glass and varnish containing various concentrations of aluminum powder were tried during this period. The thermal conductivity of water glass containing 90 weight percent aluminum powder was 5 W/(mK). However, this mixture would not adhere to salt. A 90 weight percent aluminum-varnish mixture adhered better but was difficult to spread. The thermal conductivity of the mixture is exponentially dependent on the concentration of aluminum, ranging from ~ 1 W/(mK) at 80 weight percent aluminum to 5 W/(mK) at 90 weight percent.

FUTURE ACTIVITIES

Plans will be completed for modifying the Dynatech instrument to make absolute thermal conductivity measurements. Reference materials for the comparative method standard will be obtained for testing. These will include Pyroceram 9606 from other sources, fused quartz, and pure salt if they can be obtained in the needed sizes at practical costs.

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Rudkin, R. L., 1963. Thermal Diffusivity Measurements on Metals and Ceramics at High Temperatures, USAF Report No. ASD-TDR-62-24, Part II, pp. 1-16.

WBS 1.4.2

PROJECT: Bench Scale Salt Creep Tests, Phase III

PRINCIPAL INVESTIGATOR: South Dakota School of Mines and Technology (C. A. Kliche)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objective of this program is to provide bench scale, time-dependent deformation data on dome rock salt. These data will be used by other research groups to check existing computer codes on models that predict stress-induced deformation.

A method for measuring deformation of rock salt using photoelastic stress-strain measuring techniques and brittle coating techniques is to be developed.

PROGRESS REPORTED PREVIOUSLY

This project began on 1 July, 1979. Previous progress was reported in three areas:

1. Laboratory scale testing of Jefferson Island rock salt was done using brittle coating and photoelastic measurement techniques. The tests compared results of strain gage and photoelastic stress-strain measurement methods. Some correlation between strain gage and photoelastic testing was indicated in the results.
2. It was determined that, although brittle coatings are useful for testing machine parts and other metal or plastic materials, they are not suited for rock salt testing. Brittle coating is not as durable as photoelastic techniques, does not lend itself to creep measurement, and only gives threshold levels and not a true strain measurement.
3. The biaxial load frame has been pressure tested to assure that no undue bending will occur. The load frame has been disassembled and stored until the first biaxial block is ready for testing.

ACTIVITIES DURING THE REPORTING PERIOD

An 8-inch (0.20-meter) diameter hole was drilled through the block to be used for the biaxial test. The hole was drilled in order to obtain hole closure data for the block during the test.

A smooth finish was applied to the sides of the block. Four sides of the block have been sanded, and two sides remain.

Activities began and continue on the photoelastic phase of project. A photoelastic sheet was attached to a 6-inch-diameter salt specimen, and the bond was tested for adhesion. An ultimate compressive strength test was conducted on a 7 1/2-inch-diameter by 11 3/8-inch-long salt specimen. Two pieces of photoelastic sheets were bonded on a 6-inch-diameter salt specimen, and load was applied to test the continuity of fringes across the contact boundary. Results of this test show good continuity across the boundary.

Electrical strain gages of 2-inch and 1/2-inch lengths were bonded to 6-inch-diameter cylindrical salt specimens with a photoelastic sheet bonded over the gages. The test was done to study the effect of grain size on gage length.

FUTURE ACTIVITIES

Work being done on sample preparation for the biaxial test should be finished in April. After sample preparation, the next step is to place the block in the biaxial frame and then attach strain gages to the block. Finally, the gages will be hooked up to the data aquisition equipment.

More tests will be conducted on specimens with photoelastic material bonded over strain gages in order to find a solution to the problem of non-uniform fringes near the terminals.

Rectangular salt specimens, approximately 10 inches thick, 3 inches high, and 4.5 inches wide with and without holes in the center, will be tested in a spring loaded creep testing frame to study creep effects using photoelastic measurements.

WBS 1.4.2

PROJECT: Transient Creep in Rock Salt

PRINCIPAL INVESTIGATOR: Texas A&M Research Foundation (J. Handin)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objectives are to (1) develop a transient creep constitutive relation for rock salt based on operative deformation mechanisms, (2) measure, experimentally, the state variables required for evaluating transient creep theories, and (3) determine the deformation mechanisms during transient and steady-state creep of rock salt.

PROGRESS REPORTED PREVIOUSLY

These tasks have been performed: (1) constant strain rate tests on warm-pressed, synthetic aggregates of pure halite at $10^{-4}s^{-1}$, 100, 200, and 300 C, and at confining pressures of 50, 100, and 200 MPa, and tests of homogeneous mixtures of halite and anhydrites at $10^{-4}s^{-1}$, 200 C, and confining pressures of 10, 100, and 200 MPa; (2) development of one- and two-mechanism fits to the experimental data, and (3) observational work on the structural characterization of the experimentally deformed synthetic aggregates and of natural rock salt specimens from the southeastern New Mexico WIPP site.

Data were gathered for constant strain rate tests on the synthetic material at 20 MPa confining pressure (at 100, 200, and 300 C), thus largely completing the experimental phase on synthetic material. This work confirmed that at these pressures and temperatures the influence of confining pressure on strength is negligible. Temperature is by far the more important variable. In addition, deformation mechanisms also appear to be independent of these same confining pressures and probably also of the temperatures.

ACTIVITIES DURING THE REPORTING PERIOD

The following activities took place:

1. Application of the one- and two-mechanism fits to the experimental data on warm-pressed, synthetic specimens;
2. Comparison of the experimental data with those of other workers;
3. Presentation of the subgrain size versus differential stress data, including those for stress-relaxation tests, and comparison of these data with other data for experimentally deformed natural rock salt;
4. Deformation of synthetic specimens at 25 C and confining pressures of 0, 20, and 100 MPa;
5. Structural characterization of rock salt specimens from Avery Island (obtained from RE/SPEC) that will be experimentally deformed in the new large-specimen apparatus; and its use in the new large-specimen apparatus.

Significant Results

Two major conclusions seem to be emerging from the work:

1. At the conditions of these experiments and those of other workers (P_c of about 5 to 200 MPa, T to 300 C) the quasi-steady-state strength of rock salt (differential stress at 10 percent strain) is essentially independent of confining pressure. Temperature is by far the more important factor controlling strength and ductility.
2. Comparison of results from synthetic rock salt with those of other workers on specimens of natural rock salt indicates that the mechanical properties and behavior of rock salt, down to the level of the dislocation, appear to be independent of

significant differences in grain size, minor impurities, and previous history (natural versus the warm-pressing used in producing synthetic aggregates).

Comparison of Data

A comparison of steady-state stress (the differential stress at 10 percent strain) has been made with other results and the stresses compare well. The results should ultimately give the best values for the activation energies and stress exponents. Fits of theoretical equations to the transient regime data of the experiments are being obtained which should give accurate and consistent values of the steady-state stress instead of using the stress value at a particular total strain.

Subgrain Size Versus Stress

At the pressures, temperatures, and strain rates employed in these experiments, those of other workers, and in most cases of natural deformation, rock salt deforms primarily by crystal plastic mechanisms (primarily translation gliding on {110} <1$\bar{1}$0>), promoted by movement of slip dislocations. When dislocation climb becomes important, the dislocations within a crystal become arranged into walls (subgrain boundaries) where they are densely spaced compared to their so-called "free-dislocation density" between these walls. Thus subgrains are produced and the whole crystal is said to be polygonized.

One of the significant breakthroughs in structural petrology over the past five years has been the recognition that, during experimentally induced syntectonic recrystallization, completely recrystallized grains (neoblasts) and subgrains in polygonized grains equilibrate such that their average sizes are inversely proportional to the steady-state differential stress. Subgrain size data for 13 synthetic specimens show that the relation between average grain size (D, μm) and steady state differential stress (σ, MPa) is

$$D = (146 \pm 27)\sigma^{-1}; \ R_{ms} \ \mathrm{Err} = \pm \ 3.5\mu\mathrm{m}.$$

This relationship is essentially independent of confining pressure and probably also of temperature, at least from 100 to 300 C. Important to inferences about natural stresses, subgrain sizes do not change during five stress-relaxation tests at P and T of about 1,800 s each, i.e., subgrain sizes reflect the maximum steady-state differential stress. Upon addition of eight subgrain-size versus stress data points from experimental creep tests on natural rock salt, the relation becomes

$$D = (150 \pm 77)\sigma^{-1}; \ R_{ms} \mathrm{Err} = \pm \ 9.0\mu\mathrm{m}.$$

There are two important points about these findings to emphasize at this time:

1. The D-σ relation seems to be the same for both types of experimentally deformed material, synthetic and natural rock salt.
2. A potentially useful petrofabric tool for study of natural rock salt is emerging.

FUTURE ACTIVITIES

During the forthcoming quarter, plans are to (1) calibrate and put into operation the new large specimen apparatus; (2) continue the structural characterization of experimentally deformed material; and (3) analyze the stress-strain-time data on simulated rock salt pillars and compare the results with those of others.

WBS 1.4.2

PROJECT: Salt Model Pillar Studies

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (T. F. Lomenick)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objective of this work is to provide data for the proper design of excavated cavities in rock salt repositories which are candidates for the storage and disposal of radioactive wastes.

PROGRESS REPORTED PREVIOUSLY

Preliminary examinations of long-term creep tests were made.

ACTIVITIES DURING THE REPORTING PERIOD

The equipment and material needs for upgrading the salt model testing laboratory at ORNL have been evaluated at the request of ONWI. The long-term tests are continuing.

FUTURE ACTIVITIES

Tests will continue on model salt pillars, including samples heated to 60 and 100 C.

WBS 1.4.2

PROJECT: Strain-Related Radiation Damage Measurements in Rock Salt for Waste Disposal Applications

PRINCIPAL INVESTIGATOR: Brookhaven National Laboratory (P. W. Levy)

ONWI PROJECT MANAGER: J. F. Kircher

OBJECTIVE

Nuclear radiation from radioactive waste will subject the surrounding rock to exposures ranging from the negligibly small to those producing pronounced radiation effects, particularly in rock salt. The current project has two principal objectives.

The first is to determine radiation damage in rock salt in sufficient detail to estimate the damage produced at any point in a repository as a function of rock salt type, impurity levels, water content, exposure to radiation including total dose and dose rate effects, temperature vs. time profiles and related annealing effects, rock salt strain occurring prior to and after emplacement, etc.; in addition, determine the damage formation and annealing kinetics in sufficient detail to reasonably reliably extrapolate the laboratory data to the very long times, the temperatures, the strain rates, etc., occurring in an actual repository.

The second objective is to characterize radiation damage effects in granite, basalt, tuff, shales, clays, buffer materials, etc., particularly under repository conditions. Unfortunately, very little radiation damage information is available on these materials. Also, the techniques which have provided so much useful damage data on rock salt, which is transparent, are not useful for opaque or translucent minerals. Consequently, roughly 40 percent of the current effort is devoted to the development of techniques for studying radiation damage, on the atomic defect and/or crystal lattice level, in opaque minerals. Under test are a number of previously used methods and several novel techniques such as photoacoustic spectroscopy.

PROGRESS REPORTED PREVIOUSLY

As a result of recently completed studies, a number of the most important radiation damage processes in both natural and synthetic rock salt are now reasonably well understood. Among these are dependence on temperature, total dose, and strain applied prior to irradiation. Understood to a lesser extent are the differences between natural and synthetic salt and the role of impurities in damage formation. Two important aspects not understood in detail are the dose rate effects and the effects produced by applying strain during and/or after irradiation.

One important, if not the most important, radiation damage effect in rock salt is the formation of colloidal sodium metal particles during irradiation. In unstrained or slightly strained salt, the colloid formation follows a classical nucleation and growth curve. The zero or low-growth-rate nucleation period extends to the 10^6 or 10^7 R range. The rapid growth regime extends to the highest doses tested, namely 10^9 R or more, and is well described by expressions of the form $C(t) = (\text{constant})(\text{time})^n$ or $C(t) = (\text{constant})(\text{dose})^n$. The constants and the values of n differ greatly for natural and synthetic salt and depend strongly on strain and other factors. The colloid growth rate is strongly temperature-dependent. The growth is negligible at 100 C, increases to a strong maximum at 150 to 175 C, and then decreases to a negligible level at 300 C. Most importantly, the colloid formation nucleation period is reduced by straining prior to irradiation; it is near zero for strains of 10 percent or more. At this time, the colloid concentrations that would be formed in an actual repository are difficult to estimate, but they could be in the 0.001 to 0.1 percent range.

Radiation damage, particularly colloid formation, has been studied in natural rock salt from a large number of geologic localities, including the WIPP site and Asse, FRG, and different horizons at the same site. Variations in colloid levels of ten or more are observed. The most recent paper is by Levy, Swyler, and Klaffky (1980).

ACTIVITIES DURING THE REPORTING PERIOD

Colloid Growth in Natural Rock Salt from Various Localities

To determine if the radiation damage characteristics of natural rock salt (1) are dependent on the geological origin of the salt or (2) vary among horizons at the same site, radiation damage measurements have been made on a large variety of samples. The growth of radiation-induced colloids for 14 samples is shown in Figure 1, which shows the most recent measurements. More specifically, Figure 1 shows the colloid absorption band area, in units of eV cm^{-1}, between 1.7 and 3.0 eV (730 to 410 nm) as a function of irradiation time for salt being irradiated with 1.5 MeV electrons at approximately 150 C. The measured area is approximately 97 percent of the total colloid band area. The measurements were made at a dose rate of 1.2×10^8 rad/hr (3.3×10^4 rad/sec). At large irradiation times the curves are linear. In other words, as pointed out previously, radiation-induced colloid growth is well described by $(time)^n$ or $(dose)^n$ relations.

The n values in Figure 1 were obtained from the high dose ends of the curves. The average of n for the 14 curves in the figure is 1.85, with a standard deviation of 0.18. As described last quarter, the presence of certain impurities surpresses colloid formation, i.e., the purer the crystal, the more rapid the colloid growth. This observation is supported by the fact that in very pure synthetic salt, n is in the 4 to 5 range and the n = 2.4 value for one Rocanville salt applies to a sample that may have been purified and/or contains less strain by having been recrystallized. The latest data are in accord with a previous conclusion, namely, the natural rock salt n values are in the 1.5 to 2.0 range predicted by the Jain and Lidiard theory. In contrast, the n = 4 or 5 values for synthetic salt and the n = 2.4 for recrystallized Rocanville salt are outside of the predicted range. The latest data also support a previous conclusion about the minimum dose rate required to produce colloids. Colloid formation is regularly observed in samples at dose rates that are 10 or more times less than the predicted minimum.

Thermoluminescence of Natural and Synthetic Rock Salt

Thermoluminescence (TL) measurements provide information on the different electron and hole traps that occur in solids. Often these traps are defects, and if this is so TL measurements can be used to study the introduction of defects during irradiation, their removal during heating, etc. TL studies can also be used to obtain data on electronic and other properties of solids. For example, radiation-induced colloid formation in salt depends on the negative ion vacancy concentration and diffusion coefficient. The latter depends on the charge of the vacancy. It can be uncharged or it can have trapped an electron, i.e., converted to an F-center. The diffusion coefficients of the two charge states are, almost certainly, quite different. Information on the thermal release of electrons from F-centers is obtained by studying the corresponding TL peak(s).

Well under way is a survey of the TL properties of synthetic melt-grown NaCl and rock salt from selected localities. Figure 2 shows typical TL glow curves of crystals after they were subjected to the indicated gamma ray irradiations. All curves shown are plotted with the maximum intensity at one. The curve intensities vary greatly and depend strongly on dose. The glow peaks in the 275 to 300 C range appear to be common to all

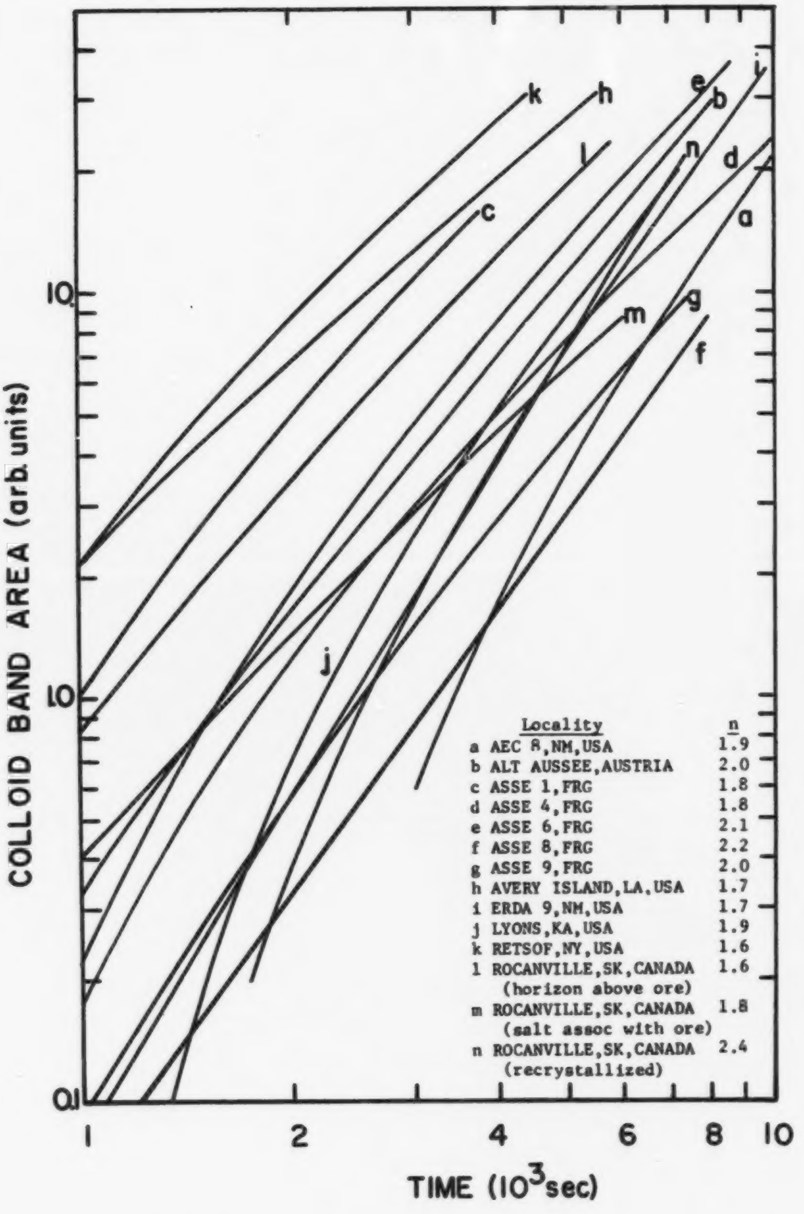

Figure 1. Radiation-Indcued Colloid Band Area Versus Irradiation Time for 14 Natural Rock Salt Samples Irradiated at Approximately 150 C with 1.5 MeV Electrons at a Dose Rate of 1.2×10^8 rad/hr (3.3×10^4 rad/sec). (These data demonstrate that colloid growth is well described by $(\text{dose})^n$ or $(\text{irradiation time})^n$ relations. The tabulated values of n were determined using a least-squares procedure at the high-dose end of the data. Variations in colloid level are related to impurity content, strain, and other factors.)

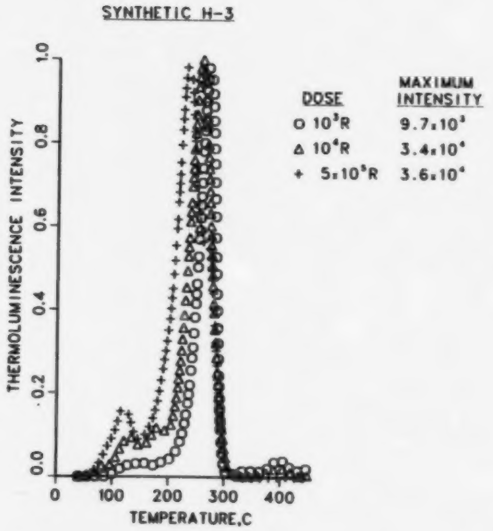

Figure 2a. Thermoluminescence Glow Curves from Synthetic Melt-Grown NaCl Crystals (Harshaw No. 3) Induced by the Indicated ^{60}Co Gamma Ray Irradiations.

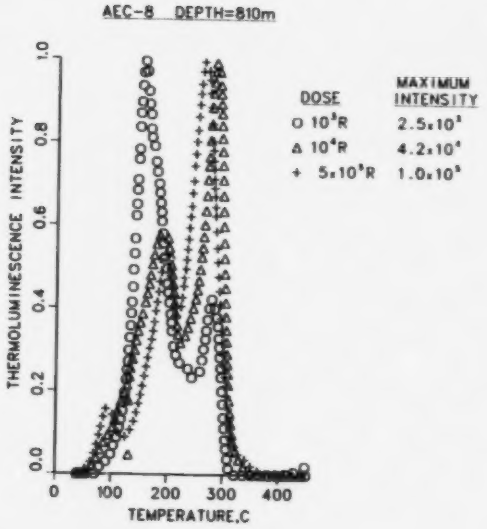

Figure 2b. Glow Curves from Natural Rock Salt, Drill Hole AEC-8 (810-meter level) at the WIPP Site, Southeast New Mexico.

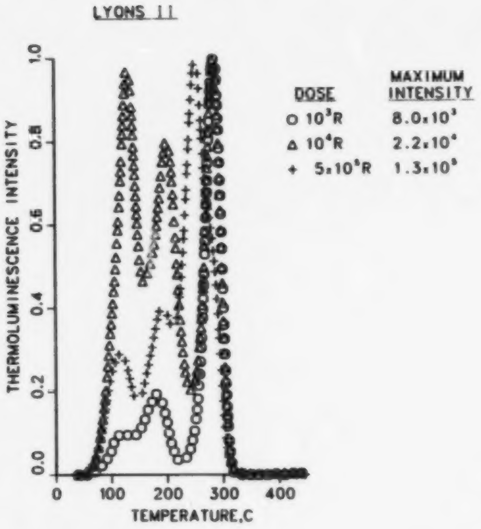

Figure 2c. Glow Curves from Natural Rock Salt from Lyons, Kansas.

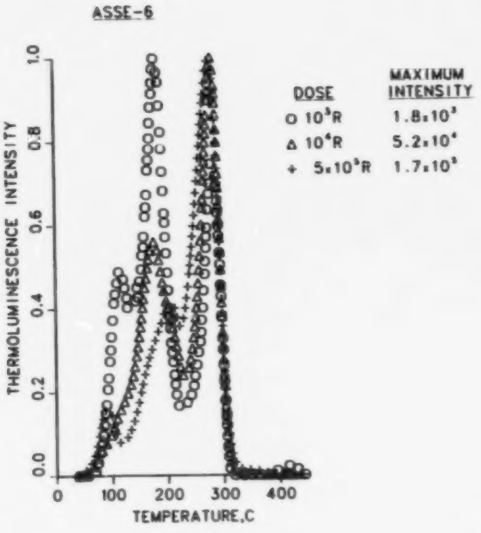

Figure 2d. Glow Curves from Natural Rock Salt from Asse, FRG (775-meter level, Strassfurt series).

samples, while peaks in the 175 to 200 C range occur only in the natural samples. At present, attempts are being made to resolve the recorded glow curves into individual glow peaks and to determine the TL kinetics of each peak.

Gas Evolution from Rock Salt and Other Minerals Before, During, and After Irradiation

The completed radiation effect studies on rock salt point to the need for additional information that could be very important for both practical and scientific purposes. It is now well established that colloid sodium metal particles form in rock salt during and after irradiation. For all of the sodium metal included in colloid particles, a corresponding amount of chlorine must be formed. For both repository engineering applications and to understand the radiation-induced colloid formation, it is essential to determine if this chlorine remains in the salt lattice or diffuses out of the crystal. To study this problem, a temperature-controlled irradiation chamber is being fitted to a mass spectrometer-type gas analyzer.

Theoretical Dislocation Studies

The objective of these studies is to determine which rock salt dislocations are likely sites for nucleating sodium metal colloid particles during irradiation. The study of defect migration to the <001> edge dislocation has previously been completed for a range of elastic constant values. A first draft of a topical report describing this study has been prepared. Studies analogous to those for the mobile <001> edge dislocation are being made for the sessile (immobile) <111> edge dislocation. As previously pointed out, the <111> dislocation is formed by the interaction of mobile dislocations on intersecting slip planes. In the last report, expressions were given for the flow lines, i.e., the paths along which the defects move to the dislocation. During the past quarter the detailed nature of the flow line solution was studied. More specifically, the dependence of the various parameters in the solution on the anisotropy parameter h (analogous to H for the <001> dislocation) was determined. Also, the solution of the continuity equation for the <111> dislocation case was begun. This equation gives the concentration of defects about the <111> dislocation as a function of time. Analogous to the calculations for the <001> dislocation, the solution of the equation of continuity for the <111> dislocation involves three sets of characteristics. The first set gives the flow lines. The second set gives the boundary of the depletion zone, i.e., the area about the dislocation which is depleted of defects and which expands with time. The third set gives the anisotropic distribution of defects outside the depletion zone. Each of these characteristics will be studied in detail.

FUTURE ACTIVITIES

The survey of radiation damage in rock salt samples from different geological localities and different horizons, etc., at each locality will continue with emphasis on samples from U.S. salt domes. Any additional time available will be used to determine how radiation damage formation in natural rock salt depends on dose rate.

Completion, testing and, if possible, the initial measurements with the equipment for studying gas evolution from rock salt and other minerals before, during, and after irradiation are planned for the next quarter.

Theoretical calculations are continuing to determine which dislocation-related properties are important for nucleating radiation-induced colloids in salt. The <111> dislocation calculation is progressing. The report on the <100> dislocation should be finished in a month or two.

The analysis of data on heat-induced colloid formation in salt irradiated at room temperature is continuing.

Analysis of the thermoluminescence data on natural and synthetic rock salt is in progress.

REFERENCE

Levy, P. W., K. J. Swyler, and R. W. Klaffky, 1980. "Radiation Induced Color Center and Colloid Formation in Synthetic NaCl and Natural Rock Salt", Journal de Physique, Vol. 41, p. 344.

WBS 1.4.2

PROJECT: Radiation Chemistry of Salt Mine Brines and Hydrates

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (G. H. Jenks)

ONWI PROJECT MANAGER: J. F. Kircher

OBJECTIVE

The objective of this program is to experimentally establish the values for $G(H_2)$ and G (accompanying oxidants) in salt mine brines and hydrates ($MgCl_2$ hydrates) under gamma irradiation at temperatures up to about 450 K, for some solutions for which the vapor pressure does not exceed about 0.3 MPa at the test temperature. The G-value is a measure of product yield during radiolysis. It is defined as molecules of product over 100 eV of energy absorbed by the system. The radiolytic products from brine irradiation may have deleterious effects on package components via hydrogen embrittlement or enhanced corrosion.

PROGRESS REPORTED PREVIOUSLY

A topical report of the work was completed and submitted for external and internal review.

ACTIVITIES DURING THE REPORTING PERIOD

Review of the draft report was completed.

FUTURE ACTIVITIES

The draft report will be revised to accommodate reviewer suggestions before editing and publication. Additional experimental work will be done as time permits.

WBS 1.4.2

PROJECT: Long-Term Monitoring and Analysis of the Avery Island Heater Experiments

PRINCIPAL INVESTIGATOR: RE/SPEC, Inc. (L. L. Van Sambeek)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

The objective of the investigations at Avery Island is to acquire thermal and mechanical salt response data that will aid in the identification and understanding of the various responses of domal salt to imposed heating conditions. The transfer of heat into the salt formation results in increased temperatures which induce thermomechanical and possibly thermochemical responses. The data obtained during these investigations will be used to either develop models describing the various responses or test existing models and assess their capabilities for describing the responses.

PROGRESS REPORTED PREVIOUSLY

RE/SPEC has installed and is operating three in situ heater tests in the Avery Island salt mine. The tests were in operation by 1 June, 1978. The design of the brine movement experiments began in February, 1979; the experiments were installed during the summer of 1979 and were in operation by 1 October 1979. One of the brine movement experiments is now in a post-test evaluation stage. Specifications and designs for the additional studies have been developed, and the experiments are in operation.

ACTIVITIES DURING THE REPORTING PERIOD

Heater Tests

The post-test evaluation of the Site A and Site B heater tests was initiated in March. The heater power level of these tests was reduced in a stepwise manner for a period of 30 days to avoid rapid cooldown of the surrounding salt which could result in thermal fracturing. Data gathering activities related to the Sites A and B heater tests were accelerated during the power reductions. The data gathered include primarily temperatures and displacements. The operation data from the Sites A and B heater tests are currently being updated to include the entire period of heating for the two tests. Operation and data gathering are continuing for the Site C heater test.

Brine Movement Studies

During the quarter, plans were made to terminate the heating and moisture collection at the Site NB (natural brine) brine movement experiment. The heater power will be reduced by about 30 watts per day for a period of 30 days beginning on 1 April, 1981. During the gradual power reduction, the sampling of the moisture collection desiccant cartridges will remain on a once-per-week schedule. Temperatures will be sampled twice daily. Permeability measurements of the brine boreholes will not be made during the power reduction.

A brine inflow model was developed to assess the validity of the moisture collection at Sites NB and SB. The expression developed for inclusion velocity is based on diffusion enhanced by temperature-dependent solubility. The results of this analysis are compared with the field measurements in Table 1. The steady-state moisture collection rates presented for Sites NB and SB were established during the operation phase of the experiments. The background moisture collected from the ambient temperature test (Site AB) was subtracted from the amount collected at each of the other two tests to determine the moisture collection due to heating. The computed moisture collection rate compares favorably with the measured rates obtained from the NB and SB experiments.

Table 1. Comparison of Measured and Analytical Moisture Collection

A. Measured Moisture Collection Results

Site	Duration of Heating, days	Duration of Moisture Collection, days	Measured Steady-State Moisture Collection Rate, grams/day	Total Moisture Gain at Steady-State Rate Days	Total Moisture Gain at Steady-State Rate Grams	Measured Moisture Gain, grams
NB	315	205	0.0175	205	3.59	8.27(a)
				315	5.51	
SB	315	235	0.0107	235	2.51	5.10(b)
				315	3.37	

B. Moisture Collection Results Determined from Analysis

Assumed Porosity, ϕ (%)	Average Brine Density, Grams/cm^3	Simulation Time, days	Computed Steady-State Moisture Collection Rate, grams/day	Total Moisture Gain at Steady-State Rate, grams
0.10	1.1915	315	0.0173	5.44

(a) After 205 days of moisture collection.
(b) After 235 days of moisture collection.

Additional Studies

The two accelerated borehole closure experiments at Avery Island were discontinued at the end of March. Both tests had been in operation at their final pressure for in excess of 100 days. Several sets of measurements were made for both tests as the core-jack pressure was reduced to 0 psi to obtain the elastic deformation of the boreholes due to unloading. The measurements were continued for the elevated temperature test, since thermoelastic deformation will occur as the core cools to ambient temperature. These measurements will continue until the core is within 1 C of the ambient temperature of 27 C.

The extended permeability measurements were concluded during March. At least two measurements were made in each of the test holes. Also, six of the laboratory backfill consolidation experiments were performed.

Of the six laboratory backfill experiments, three were performed under a confining pressure of 14 psi and three were performed under a confining pressure of 29 psi. A triaxial strain rate controlled testing machine was used for the experiments. The strain rate was set at average values of 0.30 percent min and 0.60 percent min for the 14 psi and 29 psi tests, respectively. Future planned experiments will include tests at differing confining pressures under equal strain rates.

FUTURE ACTIVITIES

The major activities next quarter will be the operation of the Phase II accelerated borehole closure measurements, the continuation of the Sites A and B post-test evaluation, and the overcore of the Site SB brine movement experiment. A report covering the entire heating phase of the Sites A and B heater tests is currently being prepared.

WBS 1.4.2

PROJECT: Rock Behavior Under Elevated Pressure and Temperature

PRINCIPAL INVESTIGATOR: Lawrence Livermore Laboratory (H. C. Heard)

ONWI PROJECT MANAGER: M. M. Lemcoe

INTRODUCTION

The overall objective of the program is to develop an understanding of rock behavior under elevated pressure and temperature such that the response in space and time of a mined cavity in these rocks can be predicted. In order to do this, measurements are made in the laboratory at simulated, deep in situ conditions. It is expected that these data will be correlated with field observations and later incorporated into a model for prediction.

TASK 1: THERMAL PROPERTIES OF ROCKS

OBJECTIVE

The objective is to determine the thermal conductivity, thermal diffusivity, and thermal expansion of candidate waste repository rocks at in situ conditions of temperature, pressure, and fluid content.

PROGRESS REPORTED PREVIOUSLY

This task started in August, 1977. Making measurements under the conditions of temperature (to 300 C) and pressure (to 100 MPa) in the presence of pore fluid required an advance in measurement state of the art for rocks; an apparatus was designed. In the course of debugging it, a run was made on an unjacketed aluminum sample that showed the basic design to be viable.

Salt was found to have little abnormal behavior associated with the presence of confining pressure. Thermal conductivity and diffusivity generally decreased with increasing temperature in the manner seen in previous testing at room pressure. Thermal expansion showed no dependence upon confining pressure.

One run has been completed on a sample of Climax Stock quartz monzonite (CSQM). Data on thermal conductivity, thermal diffusivity, and thermal expansion were taken up to 200 C and 50 MPa pressure. Preparation of a second sample of this monzonite was nearly completed. In addition, preparation of two additional monzonite samples and one fused quartz calibration sample was about one-half completed.

One topical report was submitted for journal publication, and three abstracts were submitted to national or international symposiums or conferences. A final draft was completed on a second topical report intended for journal publication.

ACTIVITIES DURING THE REPORTING PERIOD

A second run was made this quarter on a sample of CSQM. Thermal conductivity and diffusivity results are shown in Figures 1 through 3. The latest run is called Run 2 on those plots. Thermal conductivity shows a decrease with temperature and, for the first time, a dependence upon confining pressure, most pronounced at low pressure, has been observed. The difference between the thermal diffusivity in this run and Run 1 cannot be explained. Hopefully, the upcoming run on the fused quartz reference standard will clarify matters.

A significant change in the thermal conductivity measurement method occurred this quarter with the conversion from a temperature control to a power control technique. An immediate benefit of this technique has been a three-fold increase in measurement precision, and it has enabled resolution of the pressure effect shown in Figure 2.

An accident during final preparation of the fused quartz sample has necessitated a change in the work plan. One section of the quartz sample was broken during fabrication and is being replaced. In the meantime, an investigation of the effect of heavy thermal damage on the quartz monzonite is proceeding. The sample previously run, otherwise of no use because of the conditions at which its jacket failed, was heated slowly under vacuum to 300 C, the maximum temperature planned for this project. The sample has now been rejacketed and shipped out for electron beam welding. A short run will be made at room temperature only to measure the thermal properties as a function of pressure. An effect stronger than the ~10 percent change between 50 and 3 MPa seen before the vacuum heat treatment (Figure 2) is anticipated.

FUTURE ACTIVITIES

In the coming quarter, three tests are planned:

1. A brief test at 35 C on the heat-treated quartz monzonite sample.
2. A fused silica calibration test.
3. The final test on Climax quartz monzonite.

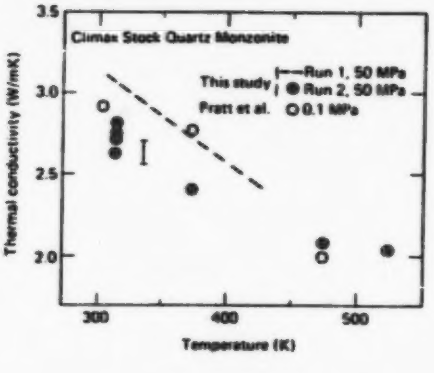

Figure 1. Thermal Conductivity Versus Temperature for Two Samples of Climax Stock Quartz Monzonite. (The error bar is the typical random error of the Run 2 data.)

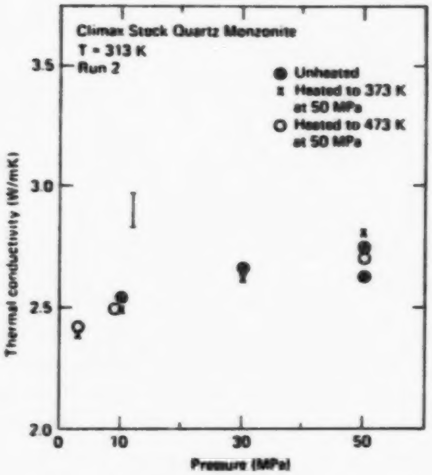

Figure 2. Thermal Conductivity Versus Pressure for Climax Stock Quartz Monzonite Run 2 at 313 K Following Various Heat Treatments. (The error bar, ± 3 percent, is the estimated measurement precision.)

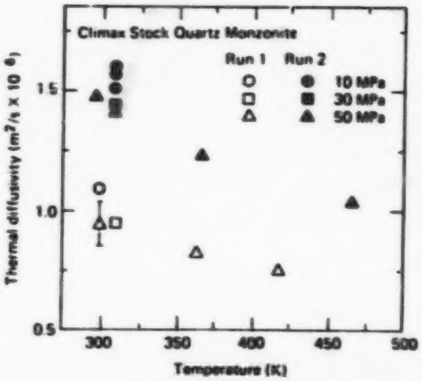

Figure 3. Thermal Diffusivity Versus Temperature and Pressure for Two Samples of Climax Stock Quartz Monzonite.

TASK 2: WATER TRANSPORT PERMEABILITY AND RELATED MEASUREMENTS

OBJECTIVE

The objective is to make systematic measurements of the permeability of intact and fractured rock as a function of confining pressure, pore pressure, and deviatoric stress. In order to extend the usefulness of the data, simultaneous measurements of fracture displacement, strain, electrical conductivity, and acoustic velocity and amplitude will also be carried out.

PROGRESS REPORTED PREVIOUSLY

This task started in June, 1976. A summary of progress through March, 1981 includes four major items.

Two complete sets of apparatus were designed and installed to determine the permeabilities of large rock samples (15 cm diameter by 28 cm long) in the range of 10^{-11} to 10^{-24} m^2. Pressures may range to in excess of 50 MPa; temperatures remain constant at 20 C. These data are taken simultaneously with the principal imposed stresses and strains, acoustic velocities and pulse amplitudes, electrical conductances, and displacement of a fracture (if present). A microprocessor system controls the test and records the data.

Measurements of the above type were completed on intact samples of Westerly granite, White Lake gneissic granite, and Creighton gabbro, and on fractured samples of Westerly granite, Stripa granite, CSQM, and Creighton gabbro. Testing had begun on an intact sample of CSQM.

Failure envelope data were completed on unfractured Westerly granite, Stripa granite, White Lake gneissic granite, Montello granite, Climax quartz monzonite, and Creighton gabbro. One sample of Stripa granite and one of Montello granite were prepared. One of the latter type of granite was fractured.

Additional permeability testing on intact samples (6 cm diameter by 10 cm long) of Climax and Stripa rock was begun in a third automated apparatus at pressures ranging to 50 MPa. Data were taken on four samples at 20 C. As more data are gathered at these conditions, testing will be extended to elevated temperatures.

ACTIVITIES DURING THE REPORTING PERIOD

Testing continued on the intact sample of CSQM in Unit 1. Reduction of the test data continued as planned. Similar testing on the intact sample of Stripa granite in Unit II also continued.

Reduction of the test data on the small samples of Stripa and Climax rocks at 20 C recently completed in Unit III yielded abnormally high values. Fluid bypass at the sample surface-copper jacket interface is suspected. A new jacketing technique using lead has been developed, and it confirmed that no bypass occurs with an aluminum dummy sample. At least one group of four Climax and Stripa samples will be rerun with lead jackets to compare with the earlier suspect data.

FUTURE ACTIVITIES

The test under way in Unit I should be completed this quarter, and the test in Unit II should be at least one-half completed. Most of the resulting data will be reduced into usable form. All 20 C testing in Unit III should be completed. Some elevated temperature tests may be started.

TASK 3: PRESSURE AND TEMPERATURE OF ROCK ELASTIC CONSTANTS

OBJECTIVE

The objective is to determine the elastic moduli of a suite of candidate repostory rocks as a function of temperature and pressure. These measurements, including Young's modulus, bulk modulus, and thermal expansion, are necessary to understand and predict repository behavior after emplacement of the waste.

PROGRESS REPORTED PREVIOUSLY

This task started in June, 1979. A summary of progress through March, 1981 includes the following major items:

1. Determination of the thermal expansion characteristics of CSQM to pressures of 27.6 MPa and 300 C. Results of this study on expansion and its relationship to in situ permeability have been published.
2. The pressure and temperature dependence of Young's modulus, bulk modulus, and coefficient of thermal linear expansion had been determined for Stripa and Westerly granites up to 55 MPa at 350 C. These data are based on nine samples: three each from the three principal directions in the parent rock. Results have been published.
3. Results similar to No. 2 above were determined for the CSQM. Measurements of this type were about two-thirds completed for Sudbury gabbro.

ACTIVITIES DURING THE REPORTING PERIOD

All remaining measurements were completed on the Sudbury gabbro. All data have been analyzed for this rock and for the CSQM. Results for both rocks were published in a topical report.

FUTURE ACTIVITIES

Preparation of a new group of test samples (basalt) will be completed, and testing may begin.

WBS 1.4.2

PROJECT: Materials Properties and Stress Measurement Techniques

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory

ONWI PROJECT MANAGER: M. M. Lemcoe

TASK 1: MATERIALS PROPERTIES TESTING PROGRAM SMALL-CORE TEST FACILITY

(N. Cook and L. Myer)

OBJECTIVE

In situ experiments in the Stripa Mine, Sweden, have yielded a great volume of data on the thermomechanical response of a granite rock mass to the heat that might be produced by buried nuclear waste. For proper analysis of the data from these experiments, it is necessary to have additional data in the form of thermomechanical properties obtained from rock samples tested in the laboratory. It is the objective of the materials properties test program to study and acquire thermomechanical properties (e.g., Young's modulus, Poisson's ratio, and thermal coefficient of expansion) using drill core from the Stripa Mine experimental areas.

PROGRESS REPORTED PREVIOUSLY

The materials testing program began in FY 79. Early in the program, work began on a stiff triaxial test machine capable of providing a confining pressure of 55 MPa, test temperatures up to 200 C, and a maximum axial load of 1.4 MN. The test cell will accommodate either 56 or 62-mm-diameter core of a length-to-diameter ratio of 3 to 1.

Fabrication and installation of the test apparatus in the laboratory was completed in the beginning of the second quarter of FY 80. This was followed by a period of transducer calibration and general machine shakedown which continued into the third quarter. Concurrently, a computer system for data acquisition and test machine control was installed. During the third quarter, suitable sample jacketing and strain-gaging techniques were also developed. Testing of intact samples of 62-mm-diameter core was begun in the fourth quarter of FY 80 and continued through the first quarter of FY 81. Preliminary results from these tests provided data on general trends in the thermomechanical behavior of the intact granite.

ACTIVITIES DURING THE REPORTING PERIOD

Several different tasks were addressed concurrently during the reporting period. The major effort was directed at installing the electric servo-control system for automatic test machine control. Recalibration of various test machine components was also carried out. Another task involved testing of an improved sample jacketing and loading piston assembly. In parallel with hardware and test machine-related activities, data analysis of tests previously completed was ongoing.

Beginning in mid-January, the test machine was dismantled for installation of the servo-controlled pumps. Installation was completed by early March.

Development of software for computer control of the loading system was completed, and tuning of the entire integrated system was under way at the end of the quarter.

Before dismantling the machine, a calibration test was carried out in which an aluminum cylinder was substituted for a rock specimen. Otherwise, all aspects of rock sample preparation and test procedure were duplicated. This test was carried out to determine the contribution of elements in the test frame to measurement of rock properties. Though the data have not yet been thoroughly analyzed, it is clear that some of the hysteresis in stress-strain curves at high confining pressure is machine-related. During machine renovation, the confining pressure transducers and table LVDT were recalibrated.

Previous samples were tested with a Teflon jacket which was limited to a service temperature of 175 C. As the maximum desired test temperature is 200 C, a sample jacket of viton was tested and performed satisfactorily at 200 C. In conjunction with the viton jacket, a new loading piston was also tested. This new piston incorporates Bridgeman Cone-type feedthroughs for routing the strain gage wires from beneath the sample jacket to the interior of the cell. The test of this piston was not totally satisfactory because some of the cones leaked.

Data reduction for the first samples tested was ongoing during the quarter. Nonlinearities in the data required computer data reduction programs capable of nonlinear regression analysis.

Preliminary thermal expansion test results were compared with results of previous similar tests on the Stripa granite. The general trend for all data is an increasing thermal expansion coefficient with temperature. However, the data from the latest tests show a higher thermal expansion coefficient at lower temperatures and a less pronounced effect of temperature on the thermal expansion.

Similar conclusions were reached in comparing other measurements; i.e., trends in the data were the same as those observed by others, but significant differences occurred in the magnitude of some properties. It is clear that further testing is required for adequate confidence in the magnitude of properties as a function of temperature and pressure.

FUTURE ACTIVITIES

With the servo-control system in operation, testing will resume and continue through the quarter. It is expected that through-put will average one to one and one-half samples per month. Both intact and fractured 62-mm-diameter samples will be tested.

One additional intact sample will be tested. Then a sample containing a healed fracture will be tested and the deformation of the intact portion of the sample compared with those of the filled fracture. Data analysis will continue in parallel with the testing. As results are acquired, they will be made available for the Stripa thermomechanical analysis.

TASK 2: STRIPA IN SITU STRESS MEASUREMENTS

(T. Doe)

OBJECTIVE

The objectives of this program are twofold: (1) to provide in situ stress data for interpretation of the heater and hydrology experiments at Stripa and (2) to compare and assess two different methods of in situ stress measurement. During 1980 the goal was to perform both hydraulic fracturing and overcoring stress measurements in SBH-4, a vertical hole drilled from the surface north of the Stripa Mine. Both types of measurements were performed from depths 100 meters or less to 300 meters.

The data obtained from the SBH-4 work will provide far-field stress values for the thermomechanical modeling of the Stripa heater experiments. The objectives of the 1981 field work are to complement the SBH-4 far-field stress measurements with near-field measurements close to the underground test areas. Hydraulic fracturing will be used in addition to USBM gage, Leeman triaxial cell, and CSIRO gage methods as a means of combining the results of different measurement methods.

The near-field underground stress measurements will play a key role in validating the mechanical numerical model of the Stripa tests.

PROGRESS REPORTED PREVIOUSLY

During the summer of 1980, a series of tests comparing the Swedish deep hole Leeman triaxial cell and hydrofracturing stress measurement techniques in SBH-4 was completed. Preliminary analyses were made at the end of FY 80, prior to availability of modulus data for interpreting the overcoring stress measurements and tensile strengths for interpreting the hydrofractures. Laboratory test data for these properties were obtained during the first quarter of 1981.

ACTIVITIES DURING THE REPORTING PERIOD

Activities consisted of completion of the data analysis of the stress measurements conducted in SBH-4 during the summer of 1980 and preparation for the stress measurements to be performed underground at Stripa during the summer of 1981.

The hydrofracturing data were interpreted using both the first breakdown technique of Haimson and Fairhurst (1978)

$$\sigma_{Hmax} = 3\ P_{s1} - P_{b1} + T - P, \qquad (1)$$

where P_{s1} = shut in pressure = Hmin

P_{b1} = first breakdown

T = hydrofracture tensile strength

P = pore pressure

and the second breakdown technique of Bredehoeft et al (1976)

$$\sigma_{Hmax} = 3\ P_{s1} - P_{b2} - P \qquad (2)$$

where P_{b2} = second breakdown pressure.

The breakdown pressures were readily determined from the pressure-time records (Figure 1); however, the shut-in pressures required some subjectivity. Previous analysts of hydrofracture data have used such criteria as the value to which pressure rapidly drops after breakdown or the stable pressure value reached a few minutes after breakdown has occurred. Both of these conditions are affected by instrumentation factors, such as the speed of the chart recorder, or fracture boundary conditions, such as intersection of another fracture. The approach used in selecting shut-in pressures in this work is based on the pressure pulse permeability test in single fractures (Wang, Tsang, Narasimhan, and Witherspoon, 1977). Considering the postbreakdown pressure behavior as a test where the fracture aperture is large at pressures greater than the in situ stress and smaller where pressures are less, then the pressure-time record should behave as a two-stage pulse test. The shut-in pressure could then be taken as a sharp break in semilogarithmic plot of the pressure versus time. Shut-in pressures obtained by this technique were in excellent agreement with the pressures required to open the fracture by slow pumping.

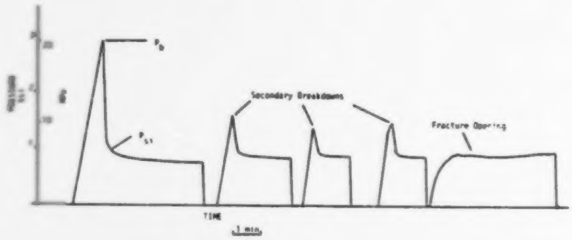

Figure 1. Typical Pressure-Time Record for Hydraulic Fracture (test 17,304.9 meters deep).

Hydrofracture tensile strength tests were run on 40 samples of core from the test zones to obtain tensile strength values for use in data analysis by Eq. 1. Half of the samples contained 1/4-inch (7-mm) holes and the other half 1/2-inch (13-mm) holes. The strengths were strongly size-dependent as the smaller hole diameter yielded strength averaging 2,355 psi (16 MPa) and the larger gave 1,860 psi (13 MPa). Presence of calcite or epidote-healed fractures lowered these values by about 25 percent.

One can extrapolate the tensile strength data to the 3-inch (76-mm) diameter size used in the field using a fracture mechanics approach similar to that of Abou-Sayed, Brechtes, and Clifton (1978). For a sample under no radial load, Abou-Sayed's breakdown equation (Eq. 17) reduces to

$$Pb = \frac{K_{1c}}{F(L/r)\sqrt{\pi L}} , \qquad (3)$$

where K_{1c} = critical stress intensity

L = crack length

r = hole radius

F(L/r) = stress intensity coefficient (from Paris and Sih, 1965, Table 7)

Given that grain size of the Stripa granite is 1 mm to 5 mm (Olkiewicz, Gale, Thorpe, and Paulsson, 1979), and assuming that failure will occur on the larger grain boundary cracks, an L of 5 mm (0.25 inch) can be used. The ratio of the tensile strengths for two borehole diameters can readily be obtained from Eq. 3 as

$$\frac{Pb \text{ at } r1}{P_L \text{ at } r_2} = \frac{F(L/r2)}{F(L/r_1)} . \qquad (4)$$

Given the average strength of 2,355 psi (16 MPa) for the 0.25-inch (7-mm) holes, Eq. 4 gives a strength of 1,950 psi (13 MPa) for the 0.5-inch (13-mm) holes and 1,280 psi (9 MPa) for the 3-inch holes in the field. The calculated strength for the larger laboratory test holes agrees well with the observed strengths. The strengths of the 3-inch holes are calculated as 54 percent of the 0.25-inch holes; Rummel and Jung (1975) observed that the ratio in their tests in limestone was about 45 percent. Whereas the failure should be expected to occur on the largest flaws available rather than on the average sized flaw, one might expect tensile strengths in the larger holes to be smaller than those calculated above. Tensile tests on large cores containing 3-inch holes are planned.

The field tensile strength, which has been defined as the difference between the first and second breakdown pressures, varied from 350 (2.4 MPa) to 1,400 psi (9.7 MPa) and averaged 750 psi (5.2 MPa). The "field" values are considerably lower than the extrapolated laboratory values, thus resulting in a lower calculation of σHmax.

In comparing the two methods of hydrofracture analysis, it should be noted that the second breakdown technique is only applicable where the ratio of the maximum to minimum horizontal stress is less than two, as for greater stress differences the second breakdown would be less than the the shut-in pressure. Furthermore, fracture opening pressure depends on the total load on the fracture wall and not just the borehole pressure. The opening of the fracture depends on the transient pressure distribution along the fracture wall and may thus reflect pumping rate as well as stress conditions.

Table 1 gives the interpolations of the horizontal and vertical stresses at the depth of the test facility based on the overcoring results and both methods of hydrofracture interpretation. The overcoring results agree well with the hydrofracturing in both the magnitudes of the minimum horizontal stress and in the orientation of the maximum horizontal stress. The overcoring results are higher than those calculated by either breakdown pressure technique. The first breakdown data, being higher, agree better with the overcoring results. The vertical stress values in excess of the overburden weight may indicate that that overcoring values are too high; however, it has been shown that the mine openings may cause an increase in vertical stress at the shallow depths where the overcoring results are also the highest.

The area of closest agreement between the stress measurement techniques is in the northwest to eastwest orientation of the maximum stress. This direction is consistent with previous data collected by the Swedish Nuclear Power Board (Hiltscher et al, 1979) and Hast (1969) in Sweden.

In conclusion, the overcoring and hydraulic fracturing results give comparable data with respect to magnitudes of horizontal stresses and to orientation. In holes where principal stress may not be coincident with borehole axes, the hydraulic fracturing may yield mainly the stresses normal to the hole rather than principal stresses. Although major questions remain both as to the cause of the scatter in the overcoring data and the question of tensile strength in hydrofracture data analysis, the overall agreement of the methods would indicate that both overcoring and hydraulic fracturing provide data applicable to practical problems in the field.

Table 1. Interpolated in Situ Stress Values at the Depth of the Test Facility (310 m in the stress borehole) in psi (MPa).

Method	σ_{Hmax}	σ_{Hmin}	σ_v(a)
Overcoring	3670 (25.3)	1650 (11.7)	1750 (12.0)
Hydrofracture (1st Breakdown)	2740 (18.9)	1550 (10.7)	1150 (7.9)
Hydrofracture (2nd Breakdown)	2390 (16.5)	1550 (10.7)	1150 (7.9)

(a) Hydrofracture values calculated from weight of overburden.

FUTURE ACTIVITIES

Preparations for the stress measurements underground will be completed, and a test plan for the experiments will be submitted to ONWI. At present the following measurements are planned: (1) overcoring measurements using the Swedish State Power Board Leeman cell in a 25 meter borehole in the full-scale drift, (2) USBM and CSIRO overcoring measurements in a 15 meter horizontal borehole under the full-scale drift, (3) hydraulic fracturing of the vertical hole used by the Power Board and an additional horizontal hole parallel to the USBM and CSIRO measurement hole, and (4) acoustic monitoring of the hydraulic fractures to determine their size and true orientation.

TASK 3: POST HEATER DRILL-BACK INVESTIGATION

(H. Wollenberg)

OBJECTIVE

The objective of this task is to investigate the effects of the now complete heating/cooling cycle on the Stripa H-10 heater borehole and adjacent granite rock mass. This is to be accomplished by the drilling and TV logging of two new boreholes intersecting the heater location. Core samples will be shipped to Berkeley for laboratory examinations.

During FY 81, the project will be completed by continuing the petrographic study of the post-test cores to detect changes in fracture parameters, microfracture intensity, fracture-filling material, and rock-forming minerals. Mechanical properties such as Young's modulus, Poisson's ratio, and the coefficient of thermal expansion for fractured and intact core samples will be measured for comparison with pretest samples. The heater hole photographic data will be analyzed to relate the three-dimensional spalling pattern to the theoretical thermal stress.

ACTIVITIES DURING THE REPORTING PERIOD

No activity took place nor is any planned for this project until April 1981.

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WBS 1.4.2

PROJECT: Swedish Cooperative Project

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (N. Cook)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

Since the field activities for the Swedish American Cooperative Project were concluded at the end of FY 80, the FY 81 effort focuses on the final documentation of field results obtained from previous year's activities.

The final documentation will include results obtained from the macropermeability, thermomechanical, and geophysical investigations and will be published as SAC reports in a form which will allow LBL, ONWI, or ONWI subcontractors to use these data for independent analytical purposes. Further, LBL will provide ONWI with geotechnical assistance on an as-needed basis for the multinational Stripa Project and/or the NWTS program in general.

PROGRESS REPORTED PREVIOUSLY

Work accomplished in the first quarter included the organization of fracture plots and stereoplots for the full-scale fracture study; transfer of thermocouple calibration data from raw data tapes to new files and plotting of same; and compilation of gage and associated thermocouple records on a hole-by-hole basis for ready inspection.

ACTIVITIES DURING THE REPORTING PERIOD

The data base resulting from fracture mapping and core logging in the full-scale heater experiment drift is available as a computer-based listing of individual fractures, as maps of the drift floor and walls, as eight vertical radial sections through each of the main heater holes, on 59 stereoplots of fracture plane poles, and in a simplified form on a 1:20 plexiglass model. This compilation of detailed fracture data will be useful in interpreting results from several experiments conducted in and near the full-scale drift, primarily the full-scale heater experiments, but also the cross-hole measurements of ultrasonic velocity and attenuation and the planned in situ determination of the state of stress.

From the draft fracture data base SAC report abstract, some of the highlights are (1) several north-south faults and several dikes cut through the H9 (3.6 kW) experiment area, but none are present in the H10 (5.0 kW) area; (2) based on observed ratios of open to closed fractures in core, epidote-coated fractures are much less likely to be opened in retrieved core and hence are stronger than calcite-coated fractures; and, (3) the degree of fracturing in the full-scale drift is intense, with an average spacing between fractures of 11 cm.

Compilation of the records of ground water infiltrating into heater and instrumentation boreholes during the operation of the three in situ heater experiments is now complete. The computer-based file consists of edited and unedited records, monthly averages, and edited and unedited plots of inflow for each borehole. The records indicate the presence of two flow components: (1) inflow attributed to local hydrological pressure gradients, and (2) water migration from cracks closing under the rapidly increasing, thermally induced stress changes. The latter component is apparent as a pulse, beginning when heaters are turned on, lasting for the following 30 or 40 days, then steadily declining over the next several months, and sharply decreasing when heater power is decreased or stopped. Total inflow per hole ranges from a fraction of a liter to over 10,000 liters over the 1 1/2-year collection period.

Computer-based calibrations of thermocouples used in the Stripa heater experiments have been plotted as differences with respect to the NBS standard calibration which was used in the reduction of the field data. Calibrations entered on data loggers have been similarly plotted. The deviations for each thermocouple class have been fitted with a mean and standard deviation to describe the deviations from NBS. Most differences fall within ± 1 C up to 100 C, and within ± 2 C up to 200 C. Since the NBS curve was to process the temperature data, this approach will set the range of measurement error for observed temperatures in the heater experiment.

Extensometer sensor performance and related data have been compiled. These records have been studied to identify sources of offsets and other anomalies in the instrument responses. Temperature profiles along extensometer rods have been plotted, some of which show evidence of water leakage into the "waterproof" conduit which houses the superinvar rods. A simulated horizontal extensometer has been operated to study the response to anchor movements.

FUTURE ACTIVITIES

Planned for the remainder of FY 81 is the completion of performance, calibration, and error assessment of the thermocouples, extensometers, IRAD gages, and USBM gages.

WBS 1.4.2

PROJECT: Stripa Testing Project

PRINCIPAL INVESTIGATOR: Swedish Nuclear Fuel Supply Co., Safety Board Division (SKBF/KBS) (Lars Nilsson, Coordinator)

ONWI PROJECT MANAGER: R. A. Robinson

HYDROGEOLOGICAL INVESTIGATIONS IN BOREHOLES

(L. Carlsson and T. Olsson,
Geological Survey of Sweden)

OBJECTIVE

The objectives of the hydrogeological investigations in boreholes are as follows:

1. Methodology development for hydrogeological and hydrogeochemical investigations in subsurface, nearly horizontal and vertical boreholes.
2. Instrumentation and equipment development in subsurface, nearly horizontal and vertical boreholes
3. Hydraulic, chemical, and isotopic characterization of the Stripa granite and ground waters.

PROGRESS REPORTED PREVIOUSLY

It was decided to carry out the investigations in at least two core-drilled boreholes, one 1,000 m deep vertical hole (V1) and one or two 300 m long nearly horizontal holes (N1 and E1). These will be drilled from a specially prepared site situated at the 360 m level in the mine. In the vertical hole, priority has been given to hydrogeochemical studies, and a minor program for hydraulic testing will follow the hydrogeochemistry.

The main purpose of borehole N1 will be to develop testing methods in horizontal boreholes regarding hydraulic and chemical properties. TV inspection and geophysical logging will also be included.

The nearly horizontal borehole E1 is justified in terms of the requirements for developing methods to measure the permeability tensor from horizontal boreholes. This borehole will, however, only be made if it is possible within the budget available for the drilling program.

ACTIVITIES DURING THE REPORTING PERIOD

The drilling of the vertical borehole (V1) has been continued down to about 506 m. The rock quality in the deepest 50 m was poor, causing problems with drilling and core logging. Due to these difficulties, it was decided to stop at 506 m and start on one of the horizontal boreholes (N1). Before any continuation of V1, the borehole must be stabilized, and the possibilities of re-entering rock of good quality must be evaluated. Different conceivable geological explanations for the zone of crushed rock are being studied.

During drilling through the zone it was observed that the water outflow from the borehole increased. At a depth of about 470 to 475 m, the outflow rose to about 48 l/min, and at the drill stop the flow was about 60 l/min. Before entering this zone, the water flow was hardly recognizable. After the drill stop, the borehole was packed off and the pressure buildup was monitored for five days. A preliminary hydraulic conductivity of $2\ 10^{-7}$ m/s was calculated out from the measurements as a mean value representative for the 50 m zone of poor rock.

Drilling of the horizontal borehole N1 has started down to about 100 m.

Rock stress measurements were made in V1 at 300 m deep. Due to the bad rock quality at 450 m, no measurements were possible.

The geophysics group at the Geological Survey of Sweden (SGU) has compiled a program for borehole geophysics and is doing one for geological analyses.

FUTURE ACTIVITIES

During the next quarter, the following activities will be performed: (1) hydraulic testing of the water-bearing zone at 450 to 506 m depth, (2) water sampling from this zone, and (3) continued drilling of N1 to full length, followed by start of borehole E1.

MIGRATION IN SINGLE FISSURE, PREPARATORY STUDY

(I. Neretnieks, Royal Institute
of Technology, Sweden)

OBJECTIVE

In this preparatory investigation various tracers, including particles of different sizes, are introduced into a single fissure in granite. The objective is to develop a reliable method for this type of investigation and to test the injection and sampling equipment that will be used in the main investigation now funded by the Stripa Testing Project. The migration distance is about 3.5 to 4 m.

ACTIVITIES DURING THE REPORTING PERIOD

Two tracer tests were done, one with Chrome-EDTA and one with Rhodamine Wt and sodium-fluorescein.

Chrome-EDTA was circulated for 72 hr with the natural pressure 0.28 MPa in the injection hole.

Na-fluorescein and Rhodamine Wt were injected simultaneously for 90 hr. The overpressure used was 0.22 MPa. The hole was flushed with clean water after the injection, and the pressure was decreased to natural pressure.

Due to the difference in water flow from the sampling holes, only water from holes No. 4 and 5 was collected. The very different flow rates to the various collecting holes indicate considerable channeling. The mean travel time for fluorescein is about 100 hr and 200 hr for holes 4 and 5.

Rhodamine is influenced in some way along the flow path as the peak height is lower than that for fluorescein. Rhodamine Wt thus cannot be used to characterize the water residence time without a knowledge of the interaction mechanisms.

FUTURE ACTIVITIES

Injections of particles and high-molecular weight Dextran are planned.

The injection and sampling equipment will be modified, and a suitable fracture for the main investigation will be located.

BUFFER MASS TEST

(R. Pusch, University of Luleå, Sweden)

OBJECTIVE

The general objective of the buffer mass test (BMT) is to verify the suitability of the suggested buffer materials under real conditions on site.

ACTIVITIES DURING THE REPORTING PERIOD

The quarter started with an evaluation of the pilot hole inflow tests to select proper sites for the heater holes and continued with production of moisture sensors, preliminary prediction of water uptake rates, and testing of bentonite samples. Heater hole drilling, manufacturing of compacted samples, and production of the comprehensive documents for ordering bulwark steel structure units, rock anchoring, etc., took place.

Instrumentation

Almost all the temperature and moisture gages with attached cables have been manufactured and prepared for installation in the mine. The BAT electronic system has been chosen for the water pressure measurement at the interface of the tunnel back-fill and confining rock.

The electronic heater control system has been checked in a three-week heater test that ended with a dismantling of a soil-surrounded heater under conditions similar to those expected in the mine.

Field Work

Drilling of the six heater holes was finished in March. Their appearance with reference to rock composition (granite) and joint frequency and width (moderate and small, respectively) is in agreement with the predictions. Geologic mapping was started in late March.

The base supports for the "backbones" of the bulwark were prepared by careful excavation of the rock.

Boreholes were drilled for the water pressure gages intended for recording water pressures at the interface of the tunnel backfill and the rock.

Other Activities

Kovari's technique for measuring small rock displacements has been chosen for recording width changes of flat and steep joints that may be caused by swelling pressures. Heater hole No. 5 is most suitable for the rock mechanical test, since it is intersected by a fairly steep water-bearing joint. This joint will be the main rock mechanical measuring object.

The prediction of rate and distribution of the water uptake in the bentonite proceeds, and the swelling pressure has now been estimated with respect to the friction along the walls of the hole. Maximum pressure against the backfill of the tunnel, or boxing-outs, is assumed to be 10 MPa.

FUTURE ACTIVITIES

The work for the next quarter will include the following: (1) casting of concrete threshold for the bulwark and an additional part of the 1.5 m slab, (2) mounting of the bulwark, (3) drilling and installation of rock anchors for all the lids, and (4) install the heaters and the back-fill in the innermost part of the drift.

WBS 1.4.2

PROJECT: Heated Block Test in Granitic Gneiss

PRINCIPAL INVESTIGATOR: Terra Tek, Inc. (M. D. Voegele)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

Excavation of a nuclear waste repository and the subsequent thermal loading superimposed on the excavation-induced stress field will cause significant changes in the stress and deformation field surrounding the repository. The objective of the heated block flatjack field test series is to obtain a data base concerning the thermal, mechanical, and transport properties of a jointed crystalline rock mass over a range of temperature and stress paths. Further objectives are to compare the test data with laboratory values and to characterize the relevant rock mass and joint sets so that results can be more readily extrapolated to other locations.

PROGRESS REPORTED PREVIOUSLY

The current project began in July, 1979. Extensive preparatory work included the design, specification, and laboratory calibration of instruments to measure stress, strain, displacement, ultrasonic velocity, and joint permeability. Baseline in situ data were obtained before drilling the flatjack slots. Following installation of the 16 m^2 of flatjacks (in duplicate to allow for failures) around the cubic block of jointed gneiss, the main series of ambient loading tests was completed. At the time of writing, one heating cycle under biaxial stress and one heating cycle under unconfined conditions have been completed.

Results summarized here incorporate the joint permeability tests performed under a range of rock and water temperatures of 12 to 74 C and a variety of biaxial stress cycles up to 6.9 MPa. Some remarkable results of hydrothermomechanical coupling are reported.

ACTIVITIES DURING THE REPORTING PERIOD

Joint Permeability as a Function of Stress and Temperature

The joint permeability tests performed at a ambient temperature (12 C) were reported previously. In the present quarter, the nine borehole heaters (Figure 1) were switched on, so as to establish two symmetrical temperature gradients across the block. The various rock temperatures operating during the flow tests are summarized in Figure 2. At the highest temperature, the rock reached 140 C in the heater plane.

The effect of stress and temperature on the theoretical smooth wall aperture (e) of the test joint was calculated from the following well-known equation for flow between parallel plates:

$$q = \frac{de^3}{12\mu} \cdot \frac{dP}{dy} ,$$

where dP/dy = pressure gradient, μ = absolute viscosity of water (1.24×10^{-3} Pa.sec at 12 C, 0.37×10^{-3} Pa. sec at 74 C), d = width of flow path, and q = flow rate. When the joint was under no load following slot drilling, the aperture (e) averaged 60 μm (0.061 mm). The various ambient load paths to 6.9 MPa closed the joint to a minimum aperture of 27.1 to 30.3 μm.

A dramatic reduction of aperture occurred when temperature was coupled with stress, as shown in Figure 3. The minimum aperture of 9.1 μm achieved at 74 C and 6.9 MPa total normal stress could probably not have been achieved by stress increase alone. Significantly, temperature had little effect on aperture when the block was unconfined.

The improved mating of opposed joint walls, apparently achieved by coupled temperature and

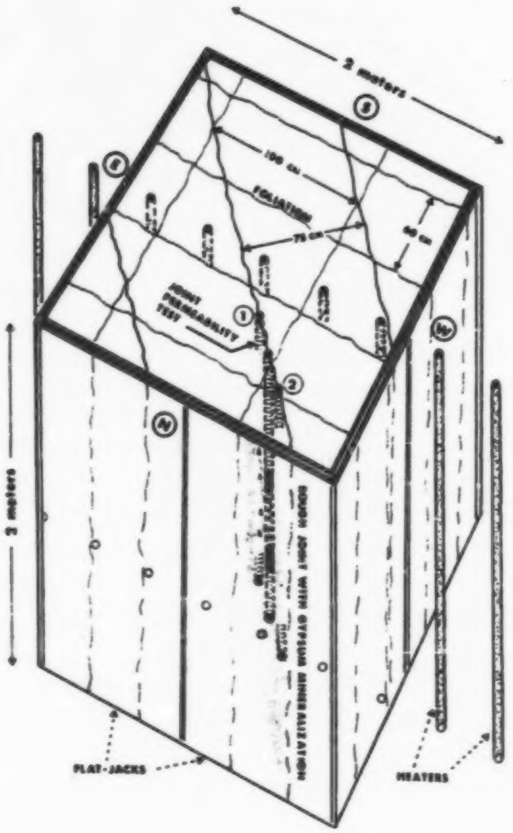
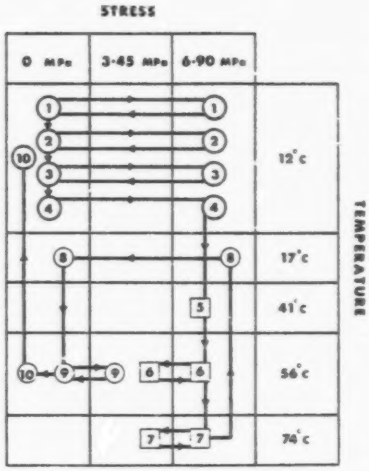

2 meters
Ⓢ
Ⓔ
100 cm
FOLIATION
75 cm
60 cm
JOINT PERMEABILITY TEST
①
②
Ⓦ
Ⓝ
2 meters
ROUGH JOINT WITH GYPSUM MINERALIZATION
FLAT-JACKS
HEATERS

Figure 1. Schematic View of Test Block Showing the Line of Heaters, the Permeability Test Location, and the Mean Joint Frequency and Approximate Orientation.



Ambient Tests

1. Equal biaxial, cycle to 6.9 MPa
2. N-S uniaxial, cycle to 6.9 MPa
3. E-W uniaxial, cycle to 6.9 MPa
4. Equal biaxial, load to 6.9 MPa

Heating and Cooling Cycles

5. Equal biaxial, 41 C
6. Equal biaxial, cycle, 56 C
7. Equal biaxial, cycle, 74 C
8. Equal biaxial, unload, 17 C
9. Unconfined, 50 and 55 C cycle
10. Unconfined, ambient.

Figure 2. Summary of Test Matrix for the Heated Block Tests.

pressure, matches that achieved by artificial tension fractures when these are created and flow-tested at the same temperatures (Voegele et al, 1981). Thermal contraction of a natural joint profile by changed conditions (i.e., cooling) probably causes a degree of misfit between the opposed asperities. In these studies, an increase in temperature of 60 C, with no change of stress, caused the joint permeability to reduce from 75 to 7 darcys. This implies a potential ten-fold increase in transport time. It is therefore concluded that elevated temperature flow tests should be an integral part of repository site characterization.

In Situ Thermal Properties

Simple numerical modeling of the temperature distribution within the block has been undertaken. An initial premise of the block test was that thermal properties could be calculated from a quasi steady-state temperature distribution. The modeling efforts included examinations of conductivity and diffusivity; of these, the diffusivity model has been more successful in predicting the temperature distribution in the block. The thermal expansion measurements have also been consistent and judged successful.

FUTURE ACTIVITIES

The heated block test matrix has now been completed, and most effort is now directed toward data reduction, interpretation of behavior, and instrument evaluation. In view of the importance of joint permeability to repository site characterization, attempts are being made to numerically model the coupled hydrothermomechanical behavior of joints using the current tests for validation. A method has been developed to incorporate the scale-dependent strength and roughness of joints (Bandis, Lumsden, and Barton, 1981). Serious consideration will be given to an extension of the heated block test matrix in order to evaluate the effects of higher stress levels (increased joint closure and/or shear) and higher temperatures.

REFERENCES

Bandis, S., A. C. Lumsden, and N. Barton, 1981. "Experimental Studies of Scale Effects on the Shear Behavior of Rock Joints", International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts, Vol. 18, pp. 1-21.

Voegele, M., E. Hardin, D. Lingle, M. Board, and N. Barton, 1981. "Site Characterization of Joint Permeability Using the Heated Block Test", U.S. Rock Mechanics Symposium, Boston.

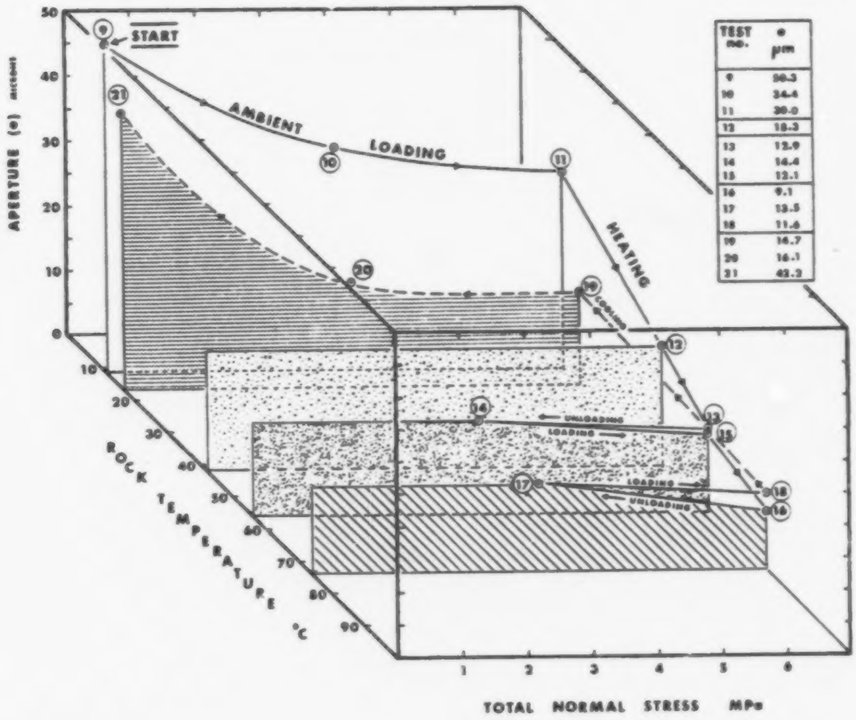


Figure 3. Biaxial Loading at Elevated Temperature Showing the Effect of Coupled Hydrothermomechanical Behavior on the Theoretical Smooth Wall Joint Aperture.

WBS 1.4.2

PROJECT: Crystalline Rock Mining Technology

PRINCIPAL INVESTIGATOR: Colorado School of Mines (W. Hustrulid)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

The Colorado School of Mines has established a research facility at its Experimental Mine located at Idaho Springs, Colorado, to develop excavation techniques and site evaluation procedures appropriate for the location, design, construction, licensing, and long-term monitoring of a hard rock nuclear waste repository. In the experimental room, a large (2 x 2 x 2-meter) block isolated from the surrounding rock by line drilling can be loaded both thermally and mechanically. These studies will furnish basic data regarding jointed rock behavior under a variety of simulated repository conditions. The block will also provide a site for equipment and calibration.

PROGRESS REPORTED PREVIOUSLY

The program began on 1 July, 1979. An experimental room was driven in the granite gneiss at the CSM Experimental Mine using careful blasting techniques. This room, which is 5 meters wide, 3 meters high, and 30 meters long, was completed in November, 1979. The principal purpose of this task was to develop excavation techniques (drill and blast) to use for driving the openings required for a hard rock repository. Two patterns of diamond drill holes (three 30-meter-long holes drilled parallel to the long axis of the room and rings of holes located at six positions along the length of the room) have been drilled to assess the degree of damage done to the rock surrounding the drift.

The radial and longitudinal drill-hole cores have been logged. The borehole walls were examined with a petroscope. Permeability measurements were conducted in the holes. Geologic structures have been mapped around the experimental room. The stress field around the room was measured, and the rock mass has been modeled by the finite-element technique. Drill-hole cores have been tested in the laboratory. Elastic properties of the rock mass were measured with the CSM cell. Instrumentation has been established to evaluate blast damage ultrasonically. Computer software and hardware have been established for analyzing data from the field experiments.

ACTIVITIES DURING THE REPORTING PERIOD

Measurements of rock-mass modulus of deformation (Er) at the experimental mine using the NX-CSM cell were completed during the quarter. The results of the tests were analyzed, and one preliminary indication is that blast damage did not exceed 1 foot from the ribs of the room, except in areas within a shear zone. The average Er is 4.54 x 10^6 psi (± 0.23 x 10^6 psi). In Figure 1, Er values are contoured around the perimeter of the experimental room at the first ring of test holes.

Three boreholes were overcored to a diameter of 6 inches. A 30-foot-long borehole was instrumented with CSIRO and USBM deformation gages besides the EX-CSM cell to measure the in situ stress field. In all, 17 tests were made with the USBM gage, and five CSIRO gages were installed in the borehole before overcoring.

A 12-foot-long concrete column with a 3-inch-diameter central hole was designed and constructed. It will be used to verify and evaluate the results of previously completed borehole injection testing to determine rock-mass permeability.

In addition, significant progress was made in a computer program to analyze the fracture data from core logging, in-hole petroscope logging, and structural mapping. This program should produce any statistical description desired for fracture quantity data comparison. Furthermore, the relative importance of particular joint sets on overall rock-mass properties will be available from the computer program results. The portion of the program that was developed during this quarter was used to analyze 269 observations from mapping in the experimental mine.

Ultrasonic pulse testing progressed well during the quarter, and all the p-wave arrival time data were gathered. Significant progress was also achieved in s-wave arrival time data measurements.

The fracture structure map of the experimental room was checked and completed during the quarter.

FUTURE ACTIVITIES

During the next quarter, the in situ stress data should be analyzed. Laboratory experiments will be conducted with the 6-inch cores recovered from the overcoring experiment to compare the CSIRO gage, USBM gage, and EX-CSM cell. Biaxial loading tests will begin using the MTS testing machine.

Rock mass permeability testing tasks for the next quarter will include completing the fracture analysis computer program, testing the concrete column, and testing pressure profiles of individual fractures. If these tasks are completed, work will be extended to variable internal packer testing, sampling undisturbed fractures for future stiffness testing, and tracer testing.

S-wave measurements will be completed, and both p- and s-wave arrival time data will be analyzed in the ultrasonic pulse-testing task. Laboratory testing of core samples to verify in-mine data will begin, and dynamic elastic constants (Poisson's ratio, Young's modulus, modulus of rigidity, and bulk modulus) will be calculated.

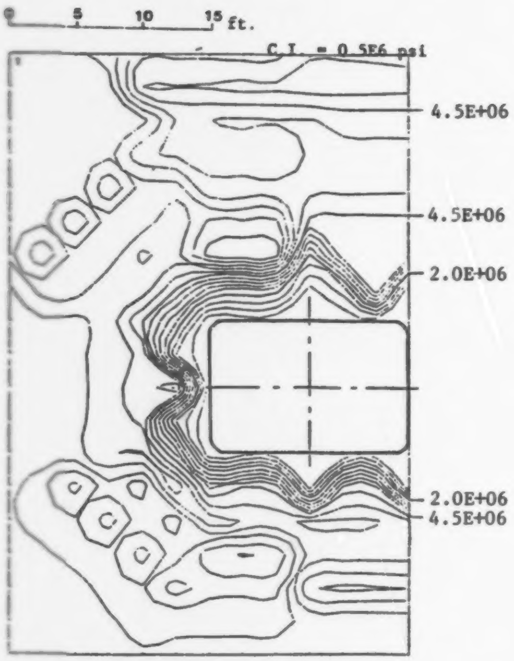


Figure 1. Rock Mass Modulus Contours (psi) (Ring No. 1)

WBS 1.4.3

PROJECT: NWTS Repository Equipment Development Plan

PRINCIPAL INVESTIGATOR: Battelle Columbus Laboratories (T. M. Trainer)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

The objectives for FY 81 and FY 82 are (1) to modify the Technology Development Plan for NWTS Repository Equipment in accord with Repository-IWG and DOE recommendations, (2) to prepare a draft Repository Equipment Test Plan, and (3) to assist the ONWI staff in preparing statements of work in accord with the Technology Development Plan.

PROGRESS REPORTED PREVIOUSLY

This project was initiated in May, 1979, to assist the Engineering Department of ONWI in developing procurement schedules for repository equipment. This effort resulted in a Preliminary Development Plan for Repository Equipment, a plan concerned primarily with repositories in salt. In FY 80 the plan was extended to include all NWTS repository processes and equipment requiring technology development. The FY 80 effort resulted in a final draft, Technology Development Plan for NWTS Repository Equipment, and a topical draft, Equipment Technology Development Required for a Nuclear Waste Geologic Repository.

FY 81 work is being directed toward (1) revising the Technology Development Plan for NWTS Repository Equipment, (2) preparing the draft Repository Equipment Test Plan, and (3) preparing draft statements of work for equipment technology development.

Work during the first quarter of FY 81 consisted of (1) distributing additional copies of the Technology Development Plan for NWTS Repository Equipment, (2) reviewing available information pertinent to repository equipment testing and further definition of the purposes of the Repository Equipment Test Plan, and (3) preparing two draft statements of work on Study of Equipment Alternatives for the Subsurface Handling of Canistered Nuclear Waste, and Reliability and Maintainability Analysis of a Canistered Waste Handling System for a Nuclear Geologic Repository.

ACTIVITIES DURING THE REPORTING PERIOD

The Technology Development Plan for NWTS Repository Equipment is currently being reviewed.

ONWI has identified the preparation of a Repository Equipment Test Plan as an important planning requirement. A comprehensive testing effort will ensure that the waste handling equipment installed at the repository will function according to predicted availability goals. This activity will be the mechanism to test all critical waste handling and excavation equipment and to identify the need for changes prior to the actual installation or use of this equipment at the repository.

The procurement activities outlined in the Technology Development Plan for NWTS Repository Equipment are extensive in complexity and time. Technical assistance in preparing these statements of work was identified by ONWI as a pressing need.

Work during the quarter resulted in the following accomplishments on the three project tasks.

Preparation of a Draft Repository Equipment Test Plan

An outline for the test plan was developed, and drafting of the plan began.

Preparation of Draft Statements of Work for Equipment Technology Development

A statement of work was drafted on Investigation of Emplacement Hole Drilling Equipment and Procedures. A detailed outline was developed for a Reliability and Maintainability Plan for Repository HLW Handling Equipment. Position papers were prepared on NWTS Plan for the Use of Codes and Standards in the Design of Geologic Repository Equipment and NWTS Plan for the Application of as Low as Reasonably Achievable (ALARA) Radiation Exposure Requirements to the Design of Repository Equipment.

FUTURE ACTIVITIES

Third quarter activities on the three tasks are expected to be as follows: (1) meetings will be held with reviewers of the Technology Development Plan for NWTS Repository Equipment, (2) work will be continued on the remaining sections of the Repository Equipment Test Plan, and (3) work will be started on a statement of work for investigating selected parameters of the retrievability of waste packages from a repository in salt.

WBS 1.4.3

PROJECT: Equipment Reliability and Maintainability Methodology

PRINCIPAL INVESTIGATOR: General Atomic Company (D. D. Orvis)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

The objective is to synthesize a methodology for equipment reliability, availability, and maintainability (RAM) analysis that can be used to establish criteria for equipment in an NWTS facility to ensure that a repository operates with high availability. This project involves study of the RAM requirements of reference facility designs and the available analysis methodologies, and then adapts those judged to be most appropriate for applicability to a waste repository. The methodology will be developed into a Guidebook that can be used by ONWI, repository contractors, design personnel, and RAM specialists. The selected methodologies are being demonstrated through evaluation of selected portions of the Conceptual Reference Repository Design (CRRD).

PROGRESS REPORTED PREVIOUSLY

This project began on 24 March 1980. An initial Guidebook draft was submitted to ONWI in July, 1980. Following ONWI review, more emphasis was placed on qualitative analysis and design guidance to refining the quantitative methodology. In refining the methodology, the following examples of application of RAM methodology to CRRD systems were developed: failure mode and effect analysis, reliability block diagram, fault-tree analysis, and maintainability studies.

The second working draft of the Guidebook was submitted to ONWI in December, 1980. It consists of two volumes. Volume 1 presents the overall RAM methodology recommended for the NWTS program. Volume 2 expands the quantitative methodology described in Volume 1. It also includes a description of recommended computer codes.

ACTIVITIES DURING THE REPORTING PERIOD

All program requirements have been completed. Principal activities in this quarter were the preparation of the Final Report and the resolution of comments on the Guidebook. The Final Report presents a summary of the work performed and a rationale for developing the style and content of the Guidebook, which documents the recommended methodology for applying reliability and maintainability for the needs of the NWTS repostory program as defined in the program objective.

The Guidebook provides a detailed explanation of a methodology for incorporating operational reliability, availability, and maintainability into repository equipment design and design documentation.

The scope of the Guidebook is threefold:

1. To provide a methodology for NWTS program management and their prime subcontractors to incorporate and control RAM considerations and to establish bases for making program decisions and committing resources.
2. To provide a methodology that system and equipment designers can apply to their products without using complex mathematical methods to systematically improve the RAM characteristics.
3. To provide a succinct, yet suitably comprehensive methodology for quantitative RAM analysis to establish a program standard (common basis) that can be employed by RAM specialists who are enlisted to assist in the evaluation of reliable designs and criteria development.

FUTURE ACTIVITIES

This project has ended. No further work will take place.

WBS 1.4.4

PROJECT: Directional Antenna

PRINCIPAL INVESTIGATOR: Lawrence Livermore Laboratory (M. Buettner and L. Ramspott)

ONWI PROJECT MANAGER: A. Andrews

OBJECTIVE

The overall objective is to construct a directional antenna system, usable within a single borehole, for locating anomalies near the borehole. The goals are to:

- Show experimentally that miniature, directional antennas can be produced by enclosing the antenna elements in a sheath made of a ferrite or ferroelectric material
- Provide an assessment of the most appropriate sheath materials.

PROGRESS REPORTED PREVIOUSLY

An experiment was conducted at Gold Hill, Colorado, in October. The radiation pattern for the ferrite-loaded dipole antenna was measured in granite.

A letter entitled "Compact, Directional VHF Antennas", based on efforts to date, was published (Buettner, 1980).

Modeling the finite cylinder problem began with the aim of predicting the radiation pattern for the ferrite-loaded dipole antenna.

Possible techniques for determining the complex permeability (μ^*) and permittivity (ϵ^*) for ferrites and ferroelectrics were examined.

ACTIVITIES DURING THE REPORTING PERIOD

Analysis of predicted system performance began. A computer code which models the complete system was written, and debugging began.

A computer code was written to model the finite cylinder problem. This code is now being debugged.

Both μ^* and ϵ^* were determined for the ferrite used in the directional antenna. The values agree well with those found in the literature for similar materials. See Figures 1 and 2 for plots of μ^* and ϵ^* versus frequency.

The input impedance was measured in a borehole at Livermore for the ferrite-dipole antenna used at Gold Hill. The resonant frequency and input resistance at resonance were found to be relatively independent of the medium in which the antenna was immersed and were 250 MHz and 125 Ω, respectively.

FUTURE ACTIVITIES

During the next quarter, the following tasks are planned:

1. Debug the finite cylinder code and run some test cases.
2. Debug the Directional Antenna, System Performance Code, and run some test cases.
3. Construct a system at Livermore for determining μ^* and ϵ^* for the directional antenna materials.
4. Determine reliable values for ϵ^* for samples of $BaTiO_3$ in the frequency range 20 to 200 MHz.
5. Design an appropriate downhole antenna alignment system for the directional probe.

REFERENCE

Buettner, H. M., 1980. "Compact, Directional VHF Atnennas", Electronics Letters, Vol. 16, No. 25/26, p. 938.

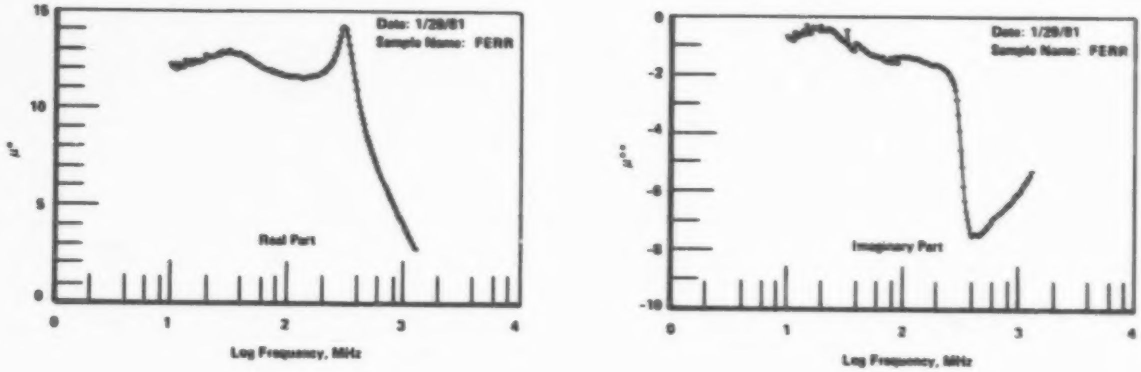


Figure 1. Complex Permeability Versus Frequency for a Ferrite.

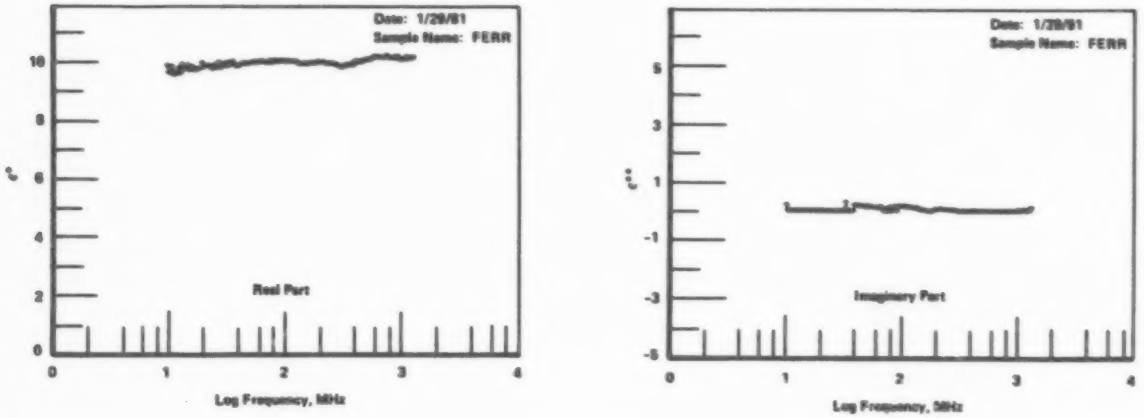


Figure 2. Complex Permittivity Versus Frequency for a Ferrite.

WBS 1.4.4

PROJECT: Data Transmission Alternatives

PRINCIPAL INVESTIGATOR: TRW, Inc. (P. Alexander)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

The objective of this project is to develop and analyze techniques to transmit, to the surface, sensor data collected within, or adjacent to, a subsurface nuclear waste repository without breaching the geologic integrity. The transmission system should be compatible with a wide variety of undefined measurement techniques and adaptable to the geologic media encountered in all candidate repositories. Four subobjectives support the overall objective:

1. Establish which performance requirements are most critical to the success of long-term monitoring systems.
2. Review the prototype long-wavelength wireless telemetry system and systematically identify its strengths and weaknesses and those of its major subsystems.
3. Identify and conceptualize alternative data transmission ideas and similarly analyze their strengths and weaknesses.
4. Analyze and compare all candidate systems relative to the established critical performance requirements, recommending those systems indicating superior performance for long-term repository monitoring.

PROGRESS REPORTED PREVIOUSLY

This project began on 16 June, 1980. The critical system performance requirements task was completed during the second quarter to the point of delivering an oral presentation of the results and submitting a draft report. Two more tasks were initiated: a review of the prototype long-wavelength wireless telemetry system and the identification and conceptualization of alternative data transmission concepts.

The work performed subsequently included the development of written descriptions of the various data transmission concepts under consideration.

ACTIVITIES DURING THE REPORTING PERIOD

The data transmission system concepts were evaluated, and transmission system operational characteristics were developed for these systems. These were then screened against the critical system performance requirements. The concepts that met the critical performance requirements (or could meet them with a limited amount of additional development) were ranked against the transmission system design considerations.

The mechanically linked transmission concepts have the advantage of being able to transmit data to the surface using a direct coupling resulting in low signal loss. They suffer the disadvantage of increasing the likelihood of radionuclide migration by creating a disturbed pathway through the rock linking the repository to the surface.

The mechanically unlinked transmission approach has the advantage of minimizing the likelihood of radionuclide migration from the repository by not creating a path between the repository and the ground surface. On the other hand, the lack of such a link means that the transmitted signals will be subjected to high loss in the rock layers between the repository and the surface.

Data transmission concepts must meet certain categories of specifications.

- The repository operational sequence
- The repository environment

- Data rates per room in the repository
- Lifetime reliability values for the data transmission system.

Two concepts, the combination hardwire plus fiber optical data link and the metallic hardwire data link, were judged to meet the data transmission critical system performance requirements. The rationale supporting this conclusion is provided in the project final report.

FUTURE ACTIVITIES

This project will be completed during the next quarter. The final report has been submitted in draft form to ONWI for review.

WBS 1.4.4

PROJECT: Monitor for Detecting Nuclear Waste Leakage in a Subsurface Repository

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (S. Klainer)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

A new ultrasensitive analytical technique, based on the laser induced fluorescence fluorimetry (LIFF) technique, allows quantitative measurements of actinide, lanthanide, and tracer abundances in water samples with sensitivities many orders of magnitude higher than presently achieved with current analytical methods. The principal focus of the present program is to develop monitoring instrumentation for those elements in ground waters associated with nuclear waste repositories.

The monitoring system provides for two modes of analysis: (1) an in situ system which provides direct chemical measurements in natural water systems over long distances (>1 km) using fiber optics, and (2) the field laboratory system which is far more sensitive and involves (on site) LIFF measurements on these materials after they have been coprecipitated (from groundwater samples) with an inorganic material such as calcium fluoride.

PROGRESS REPORTED PREVIOUSLY

This project began 1 April, 1980. A versatile laboratory fluorimeter (fluorescence spectrometer) has been assembled which is capable of making measurements using both the fiber optic (remote) technique and the coprecipitation (high sensitivity) method. Proof of principle for the remote fluorescence measurements has been made at 0.2 km using fluorescent tracers and communication-grade fiber optics coupled to a laboratory fluorometer. In situ tracer measurements to 10^{-9}M (0.2 ppb) can be made with the present equipment. Initial results, using coprecipitation, have demonstrated lanthanide sensitivities of 10^{-6} ppb and uranium sensitivities below 2 x 10^{-6} ppb (0.002 ppt). The projected plutonium sensitivity is of the same order of magnitude or lower. A new instrument using optical filters has been constructed that is expected to allow the detection of actinide element concentrations as low as 10^{-18} M.

Remote Fiber Fluorimetry

Uranyl Ion in Solutions. Fluorescence from the uranyl ion (UO_2^{++}) in a 5 x 10^{-3} M uranium solution, irradiated with the 4130 A line from a krypton laser, has been observed using remote fiber fluorimetry. The fluorescence spectrum, along with a background spectrum, is shown in Figure 1. The transmission of the valtec (PC-10) fiber is very poor at ultraviolet frequencies, and the fiber fluoresces in the same region as the uranyl ion. The use of a fiber with improved ultraviolet transmission characteristics will improve the signal-to-noise ratio.

Absolute Calibration. The sensitivity of the remote fiber fluorimeter was characterized using a weak solution of rhodamine 6G in ethanol as the sample. The optical losses of the fiber and all coupling optics were determined independently, so that analysis of the fluorescence yielded the effective path length in the sample. The effective path length determined in these measurements was slightly less than half of the predicted effective path length based on a simple geometrical model of the irradiated sample volume. The calculations are being re-examined in the light of this discrepancy.

BEST DOCUMENT AVAILABLE

Capillary Optrodes. A fiber optical sensor probe, or optrode, is chemically specific and behaves much like an ion-specific electrode, detecting only its target compound. A number of advanced optrode designs were tested this quarter. The most promising design is the capillary optrode, in which the laser beam is coupled from the fiber into a cylindrical silver-plated tube with inside diameter comparable to the fiber core diameter. In some cases, a sapphire sphere coupled the laser light into the capillary tube, but the bulk of the testing was done on optrodes in which the capillary was simply aligned directly to the fiber end. Using a 300 μm x 12 cm capillary, improvement was obtained by a factor of five over the plain termination response. The aberration produced by the sapphire spheres seriously degrades the response of the sphere-coupled capillary variation, so that the response is only marginally higher than that of the plain termination. Work continues to obtain well-corrected miniature lenses and to improve the quality of the silver coating in the capillary. A significant improvement in the instrument sensitivity is anticipated when these steps are taken.

Coprecipitation Enhanced Fluorimetry

Plutonium. A number of plutonium samples were analyzed. A previously prepared lanthanum-trichloride ($LaCl_3$) crystal doped with Pu(III) was analyzed using a tunable nitrogen dye laser (at 77 K). A sharp absorption band was located at ∿ 5156 A that resulted in a deep red Pu(III) flourescence. A second absorption line was found at 4332 A that yielded the same red fluorescence line. Since $LaCl_3$ is deliquescent, the $LaCl_3$:Pu(III) samples must be fired in a vacuum furnace and stored in an inert atmosphere.

CaF_2:Pu(III) samples were prepared by the coprecipitation technique using $(NH_4)_2SO_3$ as a reducing agent. Samples ranging from 10^{-6} to 10^{-8} M plutonium were prepared along with blanks and scanned with both argon and krypton laser excitation lines. No intense plutonium fluorescence lines were observed.

A similar set of samples was prepared by coprecipitation plutonium with lanthanum-trifluoride and scanned with the argon and krypton lasers. No intense plutonium fluorescence lines were observed.

Uranium. Contaminated ground-water samples from the Nevada Test Site have been analyzed using the uranium coprecipitation technique. These highly saline waters gave poor analytical results when analyzed by other methods (neutron activation analysis and/or optical emission spectroscopy); the difficulties were attributed to interferences associated with the high salinities. In the present technique, the samples were diluted with distilled water (100:1 or greater), which reduced the interferences substantially, brought the uranium content down into the acceptable concentration range of the method, and resulted in reproducible results.

FUTURE ACTIVITIES

During the next quarter, the following are planned:

1. Purchase compatible ultraviolet optical fibers for remote fluorimetry measurements of uranyl solutions.
2. Construct miniature lenses and improve silver coatings for the remote fluorimetry capillary optrodes.
3. Analyze plutonium samples coprecipitated with CaF_2 and LaF_3 using a nitrogen tunable laser at liquid nitrogen temperatures.
4. Prepare and analyze plutonium samples such as CaF_2:Pu(VI), LaOCl:Pu(III), $PbCl_2$:Pu(IV), TbF_3:Pu(III), and ThO_2:Pu(IV).

WBS 1.4.4

PROJECT: Nuclear Quadrupole Resonance (NQR) Techniques to Measure Stress and Strain in Rocks

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (S. M. Klainer)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

The goal of this project is to develop a new technique to measure underground stress. The measurement of the in situ state of stress in rocks must be known to ensure the integrity and safety of underground openings. Present stress measurement techniques are costly, time-consuming, often unrepeatable, and difficult to carry out. This program uses the microscopic response of crystalline materials to stress, particularly changes in the chemical bonds that increase the electric field gradient (EFG) tensor. The EFG is observed using nuclear quadrupole resonance (NQR) or a double resonance technique involving NQR and nuclear magnetic resonance (NMR). The stress tensor can be determined from the NQR frequencies observed in the rocks surrounding a borehole.

The first phase of the project is focused on stress measurements in rock salt, and later aluminum-containing minerals will be investigated. Faster and more reliable stress measurements will be valuable in the site-selection process leading to an underground nuclear waste repository.

PROGRESS REPORTED PREVIOUSLY

The project began in June, 1980. The stress-induced quadrupole frequencies in NaCl lie in the 1 to 10 kHz region for stresses at the 10 to 100 atm level. A double resonance technique, in which the sodium NMR lines in a ca. 1,000 Gauss magnetic field are used to detect the low-frequency chlorine lines, will be used first. Calculations show that there will be adequate sensitivity and signal-to-noise ratio. Resolution should be a few atmospheres or better.

A versatile NQR/magnetic resonance spectrometer (which can also be used in double resonance) was designed using advanced electronic circuits to achieve maximum flexibility and sensitivity. It will operate from 0.5 to 16 MHz initially. The specifications and detailed circuit drawings have been completed.

ACTIVITIES DURING THE REPORTING PERIOD

The final design of the major components of the NQR spectrometer has been completed, and a high-power transmitter output stage has been assembled. It has recently been tested at 3,000 watts. Having the transmitter allows work to proceed on the experimentation with and design of the tank circuit and dequeueing schemes to meet the recovery time and ring downtime specifications. Some details of the mathematical transformations required to convert information from the borehole configuration in cylindrical polar coordinates to stress information in Cartesian coordinates have been studied.

FUTURE ACTIVITIES

The signal-to-noise ratio in stressed salt will be observed using double resonance to determine more accurately the values of the gradient-elastic tensor which relates the stress to the induced NQR frequency shifts. The behavior of the gradient-elastic tensor as a function of time and as a function of strain rate will better the understanding of time-dependent phenomena in salt deformations.

Work is in progress to design an appropriate sample holder for applying stress to a single crystal of NaCl under varying conditions compatible with the requirements of a double resonance spectrometer.

WBS 1.4.4

PROJECT: Stress Displacement Measurement Techniques

PRINCIPAL INVESTIGATOR: Terra Tek, Inc. (R. Lingle)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The licensing of underground repositories for the disposal of nuclear waste requires that the computational methods used to calculate the thermomechanical response of the repository and surrounding host rock to heat generated by the nuclear waste be experimentally validated. Experimental validation, in general, requires in situ testing of repository components such as pillars. For certain applications, the test instrumentation must exhibit long-term stability in an adverse temperature environment. This instrument development program involves the modification of existing techniques or, if necessary, the development of new techniques for in situ measurement of stresses and deformation in rock salt and hard rock.

PROGRESS REPORTED PREVIOUSLY

The project began on 5 January, 1981. This is the first quarterly technical progress report.

ACTIVITIES DURING THE REPORTING PERIOD

The activities during the reporting period were concerned with completing a literature search and preparing a development plan to improve stress and displacement instrumentation based upon the results of the literature search. Both reports were submitted to ONWI in draft format; subsequent discussions with ONWI personnel and consultants suggested sources of information which had not been included in the development plan. This information has been reviewed, and it appears to reinforce the conclusions of the original documents.

Four instrument types have been identified as having the potential for development for repository use. Two are stress gages: the USBM borehole deformation gage and the CSIRO hollow inclusion gage. Two are deformation measuring instruments: the rod extensometer and the laser interferometer, which also appear to have the potential for use under repository conditions.

FUTURE ACTIVITIES

During the upcoming quarter, efforts will be directed toward finalizing the instrument development plan and starting the development phase of the test program.

WBS 1.4.5

PROJECT: Repository Sealing Project

PRINCIPAL INVESTIGATOR: D'Appolonia Consulting Engineers, Inc. (D. E. Stephenson)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The primary objectives of the penetration sealing program are (1) to develop seal designs providing safe seals at a reasonable cost, (2) to provide seal designs on schedule to satisfy overall repository licensing requirements, and (3) to provide coordination and interfacing with the other ongoing repository sealing studies being performed in the laboratory and at ONWI field sites.

PROGRESS REPORTED PREVIOUSLY

This project was initiated on 6 November, 1978. The following reports have been issued:

• ONWI-3	Development of Plan and Approach for Borehole Plugging Field Testing
• ONWI-15	The Status of Borehole Plugging and Shaft Sealing for Geologic Isolation of Radioactive Waste
• ONWI-55	A Repository Sealing Design Approach — 1979
• ONWI-90	An Evaluation of Generic Similarities and Differences in Requirements for Sealing Shafts, Tunnels, and Boreholes
• ONWI-108	Repository Sealing: Evaluation of Materials Research Objectives and Requirements — 1980.

Ongoing activities have included the following: (1) monitoring of (a) repository sealing field tests at Los Medaños, (b) NWTS site characterization programs, (c) BWIP repository sealing activities; (2) review of laboratory testing; and (3) review of proposed NRC and EPA regulations for HLW disposal. Preliminary seal design activities included development of simple numerical models for fluid flow through seal systems.

ACTIVITIES DURING THE REPORTING PERIOD

Field Testing Program

A letter report providing recommendations for FY 81 and FY 82 repository sealing field tests outlined a general program applicable to all sites, with emphasis given to studies of the disturbed zone. No tests were recommended for FY 81, with the exception that samples of old borehole plugs (including the plug-host rock interface) should be obtained from the Kubat Well in the Paradox Basin. Tests recommended for FY 82 include permeability testing in a borehole at Los Medaños and shaft and tunnel disturbed zone studies in salt and hard rock generic sites.

Liaison with Field Contractors

Monitoring of NWTS site characterization programs has continued. Specific activities have included a review of the permeability testing in Gibson Dome No. 1 Well in the Paradox Basin and a review of the design for a permeability testing tool.

Interface with Laboratory Testing Contractors

Test facilities were inspected, and requirements for testing seal materials were reviewed. Priorities were assigned for materials to be tested and properties to be determined. For FY 82, priority for testing will be given to Class H cements and concretes.

Progress has continued on topical reports addressing the suitability of clays and polymer concretes for repository sealing.

The Borehole Damage Simulation Tests at Terra Tek have been reviewed. Preliminary results from the plug test in anhydrite indicate a permeability of the plug system comparable to that of the Bell Canyon Test.

Evaluation of Test Needs for Shafts

A topical report, Sealing Considerations for Repository Shafts in Bedded and Dome Salt, is 90 percent complete, and test needs for shafts were addressed.

Preliminary Design Specification

Schematic designs for shaft and tunnel seals at Los Medaños have been completed. These are intended as working designs for review by ONWI, ONWI contractors, and other interested parties. As part of a continuing development of the designs, numerical models have been developed for sensitivity analyses of fluid flow through the proposed seal system.

Specifications for Sealing Instrumentation

This task has been initiated with a comprehensive review of testing to characterize the disturbed zone conducted at CSM, Stripa, and Hanford.

FUTURE ACTIVITIES

Five reports will be issued in draft form during the next quarter: Sealing Considerations for Repository Shafts in Bedded and Dome Salt, Repository Sealing Field Testing Program Plan, Repository Sealing Interim Design Report--Los Medaños Site, A Review of Clay Properties and Clay Research Applicable to Repository Sealing, and Applicability of Geothermal Polymer Concretes to Repository Sealing.

Ongoing activities will include the following: (1) preparation of a program plan for laboratory testing of seal materials, (2) continued development of the Los Medaños design, (3) review of DOE and BWIP comments on the draft Program Plan and Current Efforts in Repository Sealing for the NWTS Program, (4) continued evaluation of instrumentation requirements for penetration characterization and seal testing, and (5) monitoring of the Kubat Well reentry and site characterization at Los Medaños and other sites.

WBS 1.4.5

PROJECT: Borehole Plugging Program

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (C. L. Christensen)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The objectives of this program are:

1. To develop, test, and evaluate candidate cementitious grouts and other materials for use in and support of the laboratory and field-testing program; to assist in developing and implementing a geochemical program to ascertain and verify the long-term stability and suitability of cementitious and other materials as wellbore plugging materials.
2. To assess, develop, and modify appropriate instrumentation techniques to obtain the data required to verify plug performance.

PROGRESS REPORTED PREVIOUSLY

The current Borehole Plugging Program (BHP) was initiated in September, 1978, with full-scale operation under way by February, 1979.

Materials

The prognosis from previous work indicates that cementitious materials should provide adequate plugs. Their attractiveness stems from the availability of existing technology and their favorable economics of materials and emplacement.

One of the valuable results obtained to date shows that push-out strength tests, frequently employed in concrete testing procedures, are inadequate to assess the permeability of the interfaces between the grout and the rock. Heretofore bond strength was considered to be an indicator of plug adequacy. It has been demonstrated that a strong bond does not necessarily result in a low interface permeability.

Additionally, when grouts are tested as plug material in a candidate rock sample, the type of mix water is important. Initial testing of grouts used a brine mix water on the assumption that these plugs, when emplaced in a salt formation in a brine-filled wellbore, would result in a better bond to the formation. However, when these mixes were cast in the anhydrite rock samples of the Bell Canyon Test (BCT) plug zone, higher-than-expected permeabilities occurred at the interface due to a salt residue resulting from the cement hydration. A change to a fresh-water mix alleviated this effect and was used in the plug mix currently in place in the BCT.

While results are still being evaluated, indications are that, in nonsalt emplacements, the impact of brine mix water must be carefully assessed. Testing of this hypothesis continues at the U.S. Army Corps of Engineers WES, Vicksburg, MS. This testing is directed at determining the acceptable salinity that should be permitted in a given plugging application.

Testing

Progress reported during the previous quarter included (1) presentations on the Borehole Plugging Program and the Bell Canyon Test at the Materials Research Symposium in November and the National Waste Terminal Storage Meeting in December, (2) preparation of the Bell Canyon Test Results and Operational Reports, (3) review of the Intera consequence assessment report, (4) negotiations for the design and development of a fluid permeability testing tool, (5) continued testing of laboratory grout samples, and (6) preparation for the Potash Core Test.

ACTIVITIES DURING THE REPORTING PERIOD

Management and Design

Objective. The objective is to provide tested designs for repository plug systems and definitions of required laboratory and field tests.

Results. The Bell Canyon Test Summary Report is complete, has been reviewed by Sandia and ONWI, and will be published in April. This report gives a general overview of the test, including test techniques, analysis, the results obtained, and the conclusions drawn. A complementary report (with limited distribution) outlining operational procedures, daily drilling and working activities, and raw data logs and records is in the review stage. The Intera consequence assessment report on the needs and effects of plugged wellbores has been reviewed and returned to the author for minor revisions. It will be published at a later time as a Sandia contractor report.

The initial prototype design for a fluid permeability testing tool has been completed by Systems, Science, and Software (S^3) under contract to Sandia. A design review was held 31 March, 1981, by S^3 for representatives from ONWI, Sandia, D'Appolonia, and Woodward-Clyde Consultants. The prototype system has a design capability for measuring wellbore permeabilities in the range of 0.1 microdarcy. Plans are in progress at this time to assess the merit of continuing full-scale construction of the tool.

Materials

Objective. The materials task is concerned with laboratory development and testing of candidate cementitious mixes for repository plugs.

Results. Testing continued of the original five laboratory mixes at the four-year interval; the 10 ERDA samples at the three-year interval; and the BCT-1FF samples at the one-year interval. This testing is a continuation of the program to develop a history on aging effects with respect to specimen length and volume changes, porosity, density, dynamic modulus, compressional wave velocity, and permeability. Increased emphasis has been placed on X-ray diffraction and SEM techniques to complement the physical tests noted above.

Contact has been made with PSU and WES to coordinate geochemistry programs with WIPP needs. Investigation of salt as a plugging material has been initiated for plugging activities at the WIPP site. Further, the Sandia program on thermal structural interactions has established a testing matrix to evaluate the longer term integrity of graded salt. The Sandia program on backfill materials is also investigating the characteristics of salt-sand-clay mixtures that can be employed in repository sealing.

A preliminary recommendation for grouts to be used in the WIPP Site Preliminary Design Verification (SPDV) program was provided to DOE Albuquerque Operations Office. Liaison will be maintained with the drilling contractor as the SPDV program continues.

FUTURE ACTIVITIES

No activities are currently planned for the third and fourth quarters of FY 81.

WBS 1.4.5

PROJECT: Seal Materials Selection and Longevity

PRINCIPAL INVESTIGATOR: Pennsylvania State University (D. M. Roy)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

Any method chosen or developed to dispose of radioactive waste in the geologic environment will require various degrees of penetration of the medium with borehole, shafts, and tunnels. To ensure isolation of the wastes from the biosphere, such penetrations must be adequately sealed for extended periods of time. This program is focusing on those physiochemical and thermodynamic properties of seal materials which impact both seal-host-environment compatibility and long-term geochemical stability, culminating in seal material characterization and selection on a site-specific basis.

Prior to FY 81, these studies concentrated on using portland cement-based materials and composites with particular emphasis on their application to borehole plugging in conjunction with generic host materials. This effort has been expanded to include clay-clay composites and other alternative materials. A broader range of general host conditions and materials will be considered, along with site-specific horizons as they develop.

PROGRESS REPORTED PREVIOUSLY

The research has been carried on in two phases: (1) materials selection and evaluation, and (2) geochemical, long-term stability.

Materials Selection and Evaluation

In order to design cementitious materials to meet the criterion of an effective repository seal, the effects of composition, chemical additives, particle size, etc., must be established. Currently a range of commercially available cements, modified by the addition of reactive materials including fly ash, slag, ferrosilicon dust, and fine quartz and adjusted by various admixtures to further provide desirable handling and placement, are being studied under various water-to-cement ratios and curing conditions. Property determinations considered important to their evaluation as a plug-seal material include viscosity, compressive strength, permeability, volume change, bond strength, and heat of hydration. A review of the physical, chemical, and mechanical properties of clay-clay composites, as well as those of zeolites, was initiated as part of a preliminary evaluation of their role as seal materials and composites.

Geochemical Stability Studies

Concurrent with materials selection and evaluation, factors influencing performance and long-term stability are being examined to serve both as guidelines for further materials selection and to provide an evaluation of those which have shown desirable physical and mechanical properties. Calculation of the cement phase reaction products for which no thermodynamic data are available has been initiated. Some phase-pure materials were synthesized for precise confirmatory thermodynamic property determinations. These studies continue to be supplemented by detailed analyses of selected ancient and old human-formulated building materials.

ACTIVITIES DURING THE REPORTING PERIOD

Materials Selection and Evaluation

Cement-Based Materials. Work on cementitious materials designed to be compatible with and potentially usable in several categories of environment, including saturated and unsaturated brine, has been carried out this quarter. The mixtures contained several sources of added siliceous components of differing reactivities, silica fumes, ferrosilicon dusts, fly ash, and slag.

A first step in the mixture design involved rheological measurements to assure pumpability or flowability of the mixtures, determining both time dependence and shear rate dependence of rheological properties, as different mixture components were varied. A larger viscometer attachment than ones used previously enabled satisfactory measurements of more viscous and aggregate-containing mixtures. Materials selected for further study showed thixotropic or nearly Newtonian flow behavior and possessed sufficiently low viscosities. The materials studied included dense grouts containing mostly fines, as well as fine aggregate (sand)-containing mixtures, and were cured at a sequence of four temperatures: 27, 45, 60, and 90 C. The 28-day compressive strengths of all the mixtures were found to be very high, averaging 100 MPa (14,700 psi) for the grouts and above 90 MPa (13,200 psi) for the aggregate mixtures.

Extensive water permeability measurements were made, as this property is considered critical to potential performance. Particularly at the lower temperatures, curing time was a significant variable in developing a state of minimal permeability in the samples. However, after 28 days curing, essentially all the low-water-content mixtures (water-cementitious solid ratios $\sim$0.30) showed no flow (permeabilities below 10^{-9} darcies). In one particular mixture, significant relationship between strength and permeability was shown irrespective of curing temperature or time, and an increase in strength was associated with decrease in permeability.

Clay and Clay Composites. During the report quarter, efforts on clay and clay composite plugging and sealing materials have been focused on both geochemical stability under repository conditions and mechanical properties.

The host rock composition and the concomitant supply of material for possible reaction generate a complex problem in clay mineral diagenesis. Studies of the Los Medaños evaporite sequence indicate the presence of unusual composition chlorites and illites which give rise to the question of whether they are authigenic or merely detrital, with minor cation exchange capabilities.

An approach to understanding the reactivity of various clay minerals has resulted in a review of prior hydrothermal work for study of clay mineral stability and alteration. These experiments have yielded thermodynamic data which can be used to reveal the direction and extent of various anticipated or hypothetical clay mineral transformations; for example, based on Gibbs free-energy values, expansible smectite clays tend to react toward nonexpansible illite clays as a result of increases in temperature and/or potassium activity in solution. Other recent studies have attempted to focus on the rates of these reactions and the mechanisms involved by determining rate constants and activation energies. The effect of hypersaline brines on reaction rates is still somewhat unclear, although the presence of excess magnesium and calcium is believed to retard any smectite transformation.

The second major area of clay-clay composites investigation has been their mechanical behavior in the repository environment. Inasmuch as there has been considerable effort devoted to the engineering properties of clay materials, this literature review has attempted to single out the fundamental chemical and structural properties of clays that determine their physical behavior. The most important consideration of clay material is the nature of the clay-water interactions, i.e., thickness of the adsorbed water, rates of hydration and dehydration, and structure of the adsorbed water layer. The character of this adsorbed water layer will influence those physical and mechanical properties of the clay composites which define behavior under various moisture contents.

Zeolites. Due to their sorption and fixation properties for a variety of radionuclides, tailored zeolites have been considered as a potential component of plugging and sealing under anticipated site conditions, which may be mildly hydrothermal.

Hydrothermal interaction runs containing clinoptilolite and mordenite in conjunction with class H cement and 30 μm quartz and also with the PSU-WES experimental mixture have been completed at 100 C and at 200 to 300 C for one- and four-week periods. The solid phases of these runs are currently being analyzed.

Geochemical Long-Term Stability

Stable Cement and Concrete. Long-term studies of cementitious materials potentially compatible with rocks of the Los Medaños site are under way. The materials were selected upon the basis of shorter term test results as well as thermodynamic design. One salt- and fine aggregate-containing mixture which showed steadily increasing strength and decreasing permeability with curing time is under investigation. Research continues also on a salt-containing expansive grout formula investigated in comparative studies, to document its longer term behavior. Unrestrained and restrained specimens are being studied for comparison of mechanical phenomena in the two situations. Samples were prepared also for investigating the interaction between cement matrix and rock, using a variety of rocks from the Los Medaños area as well as generic types. Kinetic effects are being investigated through programmed studies of changes occurring at a sequence of temperatures.

Thermodynamic Properties. The stability of a phase which gives rise to potentially desirable expansive properties in cementitious seal materials, ettringite, is being examined in thermodynamic studies. The relative stabilities of this calcium trisulfoaluminate hydrate (ettringite), and of the monosulfoaluminate are compared, currently using an approach which examines the activity of water as influenced by ions in solution. The formations of ettringite and "monosulfate" according to the two reactions (1) and (2) are calculated:

$$C_3A + 25H_2O + 3\ \text{gypsum} = \text{ettringite (31 hydrate)}$$
$$C_3A + 10H_2O + \text{gypsum} = \text{monosulfate (12 hydrate)}$$

and finally, the equilibrium reaction between the two phases is expressed in (3):

$$\text{ettringite} \rightleftarrows 15H_2O + 2\ \text{gypsum} + \text{monosulfate.} \qquad (3)$$

Free energies of reaction and plots of free energy versus temperature as a function of activity of water are calculated. Using the activity of water present in a 20 percent NaCl solution (typical of some brines in the Los Medaños area), a lowering of the transformation temperature of ettringite to monosulfate by 22 C is found. The results are compared with experimental results in a study which shows an even larger effect of sodium chloride solutions in limiting the upper stability temperature for ettringite.

Ancient Concrete. Laboratory studies of ancient human-made materials as a key to expected long-term performance of similar materials are in progress. Hand specimens of cements, plasters, mortars, and concrete from the Roman, Greek, and Cypriot collections have been described, photographed, and documented. Thin sections have been prepared for petrographic microscope studies, and polished sections have been made for optical and SEM studies. X-ray diffraction data for mineral phase determination have been obtained for most of the samples, and analysis of the results is in progress. Other characterization studies, data collection, and examinations are also under way.

FUTURE ACTIVITIES

Short-term tests on aggregate-containing experimental mixtures designed for different horizons will be carried out. Longer term studies will be initiated on two experimental mixtures which show considerable promise.

Effort will be devoted to developing a model for hydration of cementitious seal materials considering variables anticipated in the borehole and shaft ambient.

Measurements of thermal conductivities of selected reference material and experimental seal material samples will be made and compared with known data. These and other data are required for the model.

Interface studies relevant to long-term stabilities will be performed on selected seal material combinations with rock types from the Los Medaños area and selected generic rocks.

WBS 1.4.5

PROJECT: Seal Materials Performance Limits and Longevity

PRINCIPAL INVESTIGATOR: Corps of Engineers, Waterways Experiment Station (K. Mather)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The Structures Laboratory will optimize proportions and materials for grouts and concretes to be used in tests to be made at the Los Medaños site and other sites, using cements, pozzolans, and admixtures with fresh water or water containing salts appropriate to render the grout or concrete compatible with significant properties of the wall rock. Expansive substances produced in grout hydration will be studied to determine the temperature range in which they can be produced and stabilized. Thermal properties, creep, and elastic and strain properties of host rocks and grouts will be investigated. Field surveillance and testing will be provided, and long-time tests of grout will be continued.

PROGRESS REPORTED PREVIOUSLY

Work began on 2 January, 1980. Specimens were cast in the task of optimizing BCT-1FF grout used in the Bell Canyon Test. The joint PSU/WES experiment to develop precision and accuracy data began.

ACTIVITIES DURING THE REPORTING PERIOD

This quarter's work focused on completing examinations of ERDA-10 grouts; examining five laboratory grouts aged 4 years and 1-year-old Bell Canyon Test specimens; continuing dynamic tests and compressive strength tests of the grouts mentioned above; collecting and testing Class H high sulfate-resistant cements; and analyzing data through 90 days for grouts made to optimize BCT-1FF. Work on chemical attack on fly ash continued.

Grouts were examined by eye, by microscope, by X-ray diffraction, and by scanning electron microscope. Dynamic tests were made by soniscope and by resonant frequency techniques. Standard ASTM procedures were used in testing four Class H high sulfate-resistant cements. The chemical attack on fly ash is yielding some improved results. Chemical attack on fly ashes from low rank coals like those now burned in an increasing area of the country turns out to be very complicated, if what is desired is to make a useful quantitative estimate of the glass, since the glass is the source of (1) pozzolanic activity that may permit exposure of grout or concrete to higher temperatures than could be tolerated without a pozzolan that also contains quartz, and (2) alumina that allows the production of the expansive product, ettringite. Methods have been described to remove all crystalline constituents except part of the quartz and mullite. Since the purpose of the study was to locate heavy and toxic elements, the drastic procedure was useful. But many other crystalline constituents are known in fly ashes from low rank coals, and they should not be destroyed and counted as part of the glass. This would lead to a serious overestimate of the quantity.

Sources of water-reducing high range admixtures that meet the requirements of ASTM C 494 (Specification for Chemical Admixtures for Concrete), Class F, are equivalent to the proprietary admixture that has been used. In one respect, irrelevant to uses contemplated by ONWI, only a very few Class F admixtures meet the full requirements of C 494; most destroy the air-void system necessary for concrete to resist freezing and thawing, an irrelevant criterion in underground applications.

Six examples of calcium sulfate hemihydrate in both α and β forms have been collected. It is expected that α-calcium sulfate hemihydrate is the most desirable form for use in grout or concrete because the water requirement of α is lower; tests will be under way soon.

The plaster that is probably desired is α-calcium sulfate hemihydrate; it is available from at least two plaster producers and from several oil-well servicing companies. It is not necessary to tie the constituents of a grout or concrete to any one proprietary product; it probably will be necessary to select the plaster by tests for water requirement.

FUTURE ACTIVITIES

Three activities are planned:

1. Tests of plaster
2. Planning and start of program on ettringite stability
3. Completion through 90 days of the report on optimization of BCT-1FF; making further experiments.

WBS 1.4.5

PROJECT: Wellbore Damage Zone Determination

PRINCIPAL INVESTIGATOR: Terra Tek, Inc.
(M. D. Voegele)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The objective of this program is to obtain experimental data on the wellbore damage zone caused by full-scale drilling operations. The extent and characteristics of the damage zone will be evaluated on five rock types. The drilling will be performed in the Terra Tek Drilling Research Laboratory (DRL) using as close as possible the same drilling parameters, bits, drilling fluids, and fluid pressures as those used in the field, and with the rock sample subjected to in situ environmental conditions. The drilling damage will be assessed by making permeability measurements before and after drilling and by dye-penetrant tests. A full-scale laboratory plug leakage test will also be performed. This effort is in direct support of ONWI's repository sealing program and is interactive with an ONWI borehole plug design contractor conducting concurrent modeling studies.

PROGRESS REPORTED PREVIOUSLY

Two rock types were added to the program, bringing the total to five: anhydrite, salt, granite, basalt, and tuff. The anhydrite and granite have been obtained, and sources for obtaining the salt and basalt have been selected. A search for tuff is under way.

Six of the anhydrite samples were drilled, and the damage test was completed. Because of the low permeability, it was necessary to do the damage test on the sample drilled with air instead of mud.

Laboratory permeability measurements and dye-penetrant inspections were initiated on the anhydrite.

The cement mix to be used for the plug flow test was obtained from Dowell Chemical Company and was identical to that used on the Sandia Bell Canyon plug test.

ACTIVITIES DURING THE REPORTING PERIOD

Sample Acquisition

The salt samples were received from Avery Island, and a block of tuff has been obtained from the upper Provo River Canyon in Utah. All 15 1/2-inch-diameter samples have been cored from the granite, basalt, and tuff blocks in preparation for drilling (the 15 1/2-inch-diameter salt cores were taken from Avery Island).

Plug Flow Test

The plug flow test has been successfully completed. The anhydrite sample was drilled a total depth of 24 inches with a roller-cone bit using freshwater mud. The drilling conditions were: 2,960 psi confining pressure, 5,290 psi ram pressure, and 2,000 psi mud (borehole) pressure. After drilling, the hole was flushed with fresh water for 30 minutes.

The vessel top end cap was disassembled to remove the drill bit. On 21 February, 1981, while the sample was at atmospheric pressure, the cement was poured into the borehole. The initial length of the cement plug was 20 inches. The vessel was immediately resealed, and after the space above the cement was filled with fresh water, it was returned to the conditions during drilling. The cement was allowed to cure under these conditions for 14 days. After this time, the sample was removed from the vessel and stored at room conditions until the vessel was again available for running the flow test.

Holes, 1/4 inch in diameter, were drilled up from the bottom of the sample to intersect the rock-cement interface at the bottom of the borehole wall. It was observed that the top of the cement had receded approximately 1 inch from its original level, leaving a total plug height of 19 inches.

On 27 March, 1981, the sample was placed back into the vessel and the flow test was initiated. The pressures again were identical to those during drilling. A fluorescent dye was added to the fresh water above the plug. Initially, it was not possible to obtain a reliable reading of the flow rate because of the air trapped in the system. The flow was allowed to continue over the weekend (approximately 60 hours) and, at the end of that time, steady flow at 5 cm^3/minute was recorded. The sample, sectioned by a saw cutting through it perpendicular to the borehole, had been infiltrated by dye at the flow zone. This clearly showed that the flow all occurred in a narrow zone at the cement-rock interface.

Permeability Tests

Laboratory permeability measurements on anhydrite have continued, but without encouraging results. It is apparent at this time that permeability measurements in anhydrite will not indicate the extent of the drilling-induced damage because of the large scatter in the permeability of the rock itself.

The results of the dye-penetrant inspections on drilled anhydrite samples have also failed to show any indication of drilling-induced damage. These negative results prompted the initiation of microscopic examinations on the anhydrite. Preliminary results indicate that the drilling-induced damage zone is of the order of a few grains dimension. A topical report on the microscopic examinations of anhydrite samples is being prepared.

Important Findings

During the reporting period, two findings have been of significance:

1. In the plug flow test, after the sample was sectioned, it was found that the dye had infiltrated the flow zone and clearly showed that the flow all occurred in a narrow zone at the cement-rock interface. This is important because it verifies a method of testing within the laboratory without the time and very high expenses required to make the same tests in the field.
2. The preliminary results of the permeability tests on anhydrite have been very encouraging. They indicate that the drilling-induced damage zone is of the order of a few grains dimension. This finding will give direction to efforts in designing seals by identifying specific problems to overcome in seal design.

FUTURE ACTIVITIES

The plug flow test sample and data will be analyzed and compared with the Bell Canyon data.

All rock samples are ready and will be drilled during the next two months.

Microscopic examinations will be included with permeability measurements and dye-penetrant inspections as part of the damage assessment program on the other four rock types.

WBS 1.4.6

PROJECT: Alternate Geologic Media Engineering Studies

PRINCIPAL INVESTIGATOR: Stearns-Roger Services, Inc. (J. C. Mattern)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The primary objective of the AGMES program is to develop conceptual design guidelines for nuclear waste repositories in selected deep geologic media other than salt. Secondary objectives are: (1) to identify and evaluate other media for further consideration based on engineering feasibility; and (2) to examine and evaluate existing conceptual designs for repositories in deep salt media to assess the changes necessary to adapt the designs to other selected deep media.

PROGRESS REPORTED PREVIOUSLY

The Alternate Geologic Media Engineering Studies (AGMES) program was started on 2 February, 1981. Consequently, this is the first quarterly report.

ACTIVITIES DURING THE REPORTING PERIOD

During this quarter, the Program Plan and the QA Plan for the entire AGMES program have been developed and submitted to ONWI.

The initial work on repository design considerations has concentrated on two aspects. The first has been a review of the existing conceptual designs for a repository. The second has been study of the NWTS-33 series of documents providing the design criteria as the primary bases for AGMES design considerations. To understand the established design criteria and identify areas of direct applicability to the AGMES project, a matrix format has been adopted for possible use.

WBS 1.4.6

PROJECT: A Study of Horizontal Emplacement in Salt

PRINCIPAL INVESTIGATOR: Bechtel National, Inc.
(D. A. Bitz)

ONWI PROJECT MANAGER: F. Djahanguiri

OBJECTIVE

The objective of this engineering study is to compare the effects of horizontal emplacement of spent fuel in canisters in a repository layout, similar to the NWTS Conceptual Reference Repository Description (CRRD) in dome salt. The CRRD design was based on vertically emplacing a single canister in a predrilled hole. This study is based on horizontally emplacing a single canister in a predrilled hole. The comparison is to be made on both a technical and an economic basis. A relative assessment will also be made of horizontal versus vertical emplacement for host rock media other than salt. The study is divided into the following technical tasks:

- Determine the impact of horizontal burial on the CRRD
- Assess the impact of horizontal burial on a basis of cost, safety, and R&D effort required
- Assess relative merits of horizontal burial in other media.

ACTIVITIES DURING THE REPORTING PERIOD

The final report was submitted to ONWI during the quarter.

WBS 1.4.6

PROJECT: Technology Development Studies for Geologic Disposal: Effects of Earthquakes on Subsurface Facilities

PRINCIPAL INVESTIGATOR: Savannah River Laboratory (SRL) (I. W. Marine)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The project objective is to evaluate the potential for seismic disruption of underground facilities. The program is divided into the following tasks:

- Review the existing knowledge to document the damage or nondamage to mines, tunnels, wells, and other underground facilities due to earthquakes, and to evaluate the significance of these data. The report documenting this damage and nondamage was published by the Savannah River Laboratory as USDOE Report DP-1513, Earthquake Damage to Underground Facilities.
- Perform a detailed mathematical analysis of displacements in the vicinity of faults.
- Through the use of numerical techniques, perform a generic study to determine the effect of an earthquake on underground facilities, with emphasis on how and to what extent seismic waves might affect or create fractures which could permit increased water circulation in the rock surrounding a repository.

ACTIVITIES DURING THE REPORTING PERIOD

The report Earthquake Related Displacement Fields Near Underground Facilities was published by SRL in July 1980. It was republished by the Office of Nuclear Waste Isolation (ONWI) during the quarter and given ONWI distribution.

A paper entitled Seismic Effects on Underground Openings was presented at the 1980 Annual National Waste Terminal Storage Program Information Meeting in Columbus, Ohio, on 10 December, 1980.

Plans and several informational mailings were made for the Workshop on Seismic Performance of Underground Facilities to be held on February 11-13, 1981, in Augusta, Georgia.

REFERENCES

Pratt, H. R., W. A. Hustrulid, and D. E. Stephenson, 1980. Earthquake Damage to Underground Facilities. USDOE Document DP-1513, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.

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WBS 1.4.6

PROJECT: Impact of Defense Waste on Repository Design

PRINCIPAL INVESTIGATOR: Los Alamos Technical Associates, Inc. (R. J. Kingsbury)

ONWI PROJECT MANAGER: R. W. Brown

OBJECTIVE

The principal objective of this project is to identify the impacts resulting from the receipt and emplacement of defense wastes on two spent fuel repository conceptual designs. High-level waste and transuranic waste are generated by the nation's defense-related programs and may be stored in the geologic repositories to be designed and constructed by ONWI.

PROGRESS REPORTED PREVIOUSLY

This project began in August, 1980, with visits to defense waste source sites and the collection of defense waste data and information.

Reviews of collected defense waste data and information have resulted in lists and a summary of the parameters, data, and comments for differing waste types, forms, and locations.

The distribution and allocation of HLW and TRU defense-related waste to hypothetical national and regional repositories have been developed and summarized. The summaries specify the existing volume of stored waste, the projected shipping schedule of defense waste canisters from an immobilization treatment facility, the total number of canisters projected at year 2020, and the total volume of immobilized waste to be emplaced by the year 2020.

Based on the available conceptual design documents, repository breakdown structures have been developed for the Conceptual Reference Repository Description and the National Waste Repository in Basalt (NWRB). These breakdown structures have been incorporated into the LATA-developed, computer-aided impact analysis methodology. The methodology has been used to systematically identify interactions between repository characteristics and key waste parameters.

ACTIVITIES DURING THE REPORTING PERIOD

The identification of interactions between defense waste characteristics and repository design features was systematically performed using a computer-aided methodology developed for this purpose. The methodology receives as input the complete breakdown structure for the repository design to be analyzed and a complete checklist of key defense waste characteristics. The methodology leads reviewers operating from computer terminals through the repository functional areas and the waste characteristics checklist. For each functional area, the reviewer indicates the existence of interaction (or lack thereof) with each waste characteristic. Such determinations of interactions are stored in the interaction data base.

Descriptions of interactions were based on detailed reviews of the specific repository design features and defense waste characteristics pertinent to each interaction. Descriptions of effects, causal factors, uncertainties, variables, and other such information were documented and entered into the data base. The data base management system has the capability to sort these interaction descriptions in accordance with sorting keys such as these:

- Interactions with specific repository functional areas (i.e., waste handling facility, shipping cask unloading area, waste hoist, etc.)
- Interactions with specific waste characteristics (i.e., specific canisters, waste type, form, etc.)
- Key interaction words and phrases (i.e., crane, ventilation, shipping schedule, etc.).

In order to determine the relative significance of the interactions between repository design features and defense waste characteristics, a simplified ranking and grading procedure was implemented. This procedure was used to categorize all interactions into groups of high, medium, and low importance to the accomplishment of repository performance objectives such as safety, cost effectiveness, and process compatibility.

The principal results of the interaction identification and analysis are the lists of interaction descriptions, sorted in accordance with the defense waste canisters under consideration and ranked with respect to their relative importance to accomplishing repository performance objectives. Individual interaction descriptions can be categorized with respect to the canisters under consideration as common to the majority of the canisters, common to two or three of the canisters, and unique to a specific canister.

These categories have considerable significance to the development of modification concepts for the repository conceptual designs. The objective of such modification concepts will be the practical receipt and emplacement of the defense wastes under consideration. Where interaction descriptions are essentially common to the majority of defense waste canisters, a common modification to the applicable repository functional area may be all that is required. Conversely, interaction descriptions that are unique to specific canisters may require an individual modification concept for the applicable repository functional area for each such canister. Interaction descriptions that are common to only a few canisters may result in only two or three modification concepts for the applicable functional area.

Complete results of the analysis of the interactions between defense waste and repository design features, including the interaction descriptions, will be presented in a topical report.

FUTURE ACTIVITIES

Follow-on project activities will develop repository conceptual design modifications and corresponding cost estimates for the most significant defense waste-repository interactions.

The approximate number of repository design modification concepts and cost estimates that can be performed within the scope of the project has been estimated as 50 for NWRB and 40 for CRRD.

Maximum meaningful results will be obtained from the development of follow-on modification concepts for the hypothetical national repositories only. In addition, as overall impacts cannot be developed for all canisters considered to date, maximum meaningful results can be obtained from the development of overall impacts for certain specific canisters.

WBS 1.4.8

PROJECT: Fractured Rock Studies Program

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory

ONWI PROJECT MANAGER: M. R. Wigley

TESTING FACILITIES FOR ULTRA-LARGE ROCK CORES

(D. Watkins)

OBJECTIVE

The principal objectives of the program are: to develop, operate, and maintain a facility for testing ultra-large specimens of rock; and currently, to investigate the hydraulic properties of fractures as they pertain to fluid transport through the rock mass surrounding underground openings. The facility consists of a large triaxial testing machine and associated control, data acquisition, and specimen preparation equipment. The testing machine can accommodate cylindrical specimens, on the order of 1 meter in diameter by 2 meters high, which can be subjected to axial loads up to 17.8 meganewtons and hydrostatic confining pressures of 5.2 MPa. The test facility provides a general capability for testing ultra-large rock specimens for a variety of purposes in support of the research and technology development needs of the Geologic Repository Program of ONWI.

PROGRESS REPORTED PREVIOUSLY

Current research is directed at studying the effect of specimen size on the measured hydraulic properties of discrete natural fractures in granite. During the first quarter of FY 81, steady-state hydraulic flow tests were conducted in a single subhorizontal natural fracture contained in an unjacketed cylindrical specimen of Charcoal Black Granite from Cold Spring, Minnesota. The diameter of the specimen was 0.91 m, with height being twice the diameter. The rock specimen and particularly the fracture were instrumented with LVDTs. Strain gages were bonded at several locations to monitor the rock deformation. A total of 39 radial flow tests were performed; each test involved applying a certain normal load on the specimen and measuring the flow rate in the fracture by injecting water into and withdrawing it from a borehole located along the central vertical axis of the specimen. Tests were repeated at each of several stages of axial loading and unloading to study the relationship between fracture-conductivity, fracture-deformation, and normal stress. On completion of the test series, the specimen was removed from the test facility. The rock fracture was anchored using a compression bolt, packed in a wooden cradle, and shipped to the quarry plant in Cold Spring for reduction of size to 0.76 m diameter by 1.52 m in height.

During the test program, the newly installed desk top computer and data acquisition system (DAS) were operated on a trial basis, in parallel with the existing data acquisition system. Due to partial failure of the old data acquisition system, some 50 percent of the data gathered had to be manually reduced to engineering units, which consumed considerable time.

The subsequent analysis showed the stress-dependent nature of the fracture flow rate. The maximum flow rate at zero normal stress was on the order of 60 cm^3/sec/MPa, and after several cycles of loading and unloading reduced to 3.0 cm^3/sec/MPa at a normal stress of 21 MPa (Figure 1). Another important finding was that repeated loading and unloading caused a decrease in conductivity, albeit with decreasing rate for any given normal stresses. The most significant finding was that the flow rate exhibited time-dependence. This necessitated a duration for some of the flow tests as long as two hours.

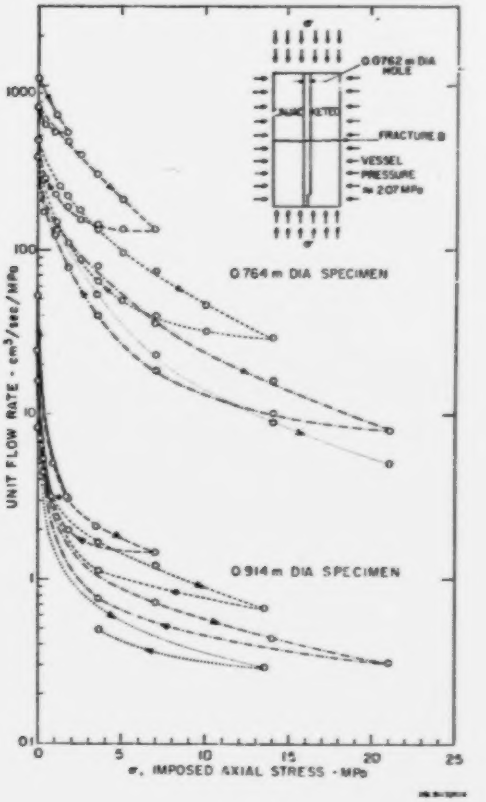


Figure 1. Unit Flow Rate vs. Axial Stress.

ACTIVITIES DURING THE REPORTING PERIOD

The Charcoal Black Granite specimen, reduced to 0.764 m diam and 1.53 in height, was received from the Cold Spring Quarry. A series of falling head radial flow tests was conducted on the main fracture to get an idea of the conductivity of the fracture, in order to choose proper instrumentation to measure the flow rate during the subsequent steady-state radial flow tests.

The rock was then instrumented with a total of 26 LVDTs to straddle the main fracture and two minor vertical fractures, and 34 strain gages were bonded on the rock to monitor the rock strain. Thermocouples were installed within the borehole and in the vessel to monitor temperature changes.

The existing system to inject water into the fracture was simplified, and the hydraulic lines which were originally plastic were replaced by stainless steel pressure tubing. This was done because it was suspected that the plastic lines under sustained water pressure may have contributed to the apparent time-dependent response.

The steady-state radial flow tests were started. The DAS was programmed to monitor the total of 80 instruments in 0.1 second. Scanning interval was generally 30 seconds during the test period and 30 minutes during night-time holding periods.

In five days 64 flow tests were performed. The tests were conducted by injecting water through the central borehole at each of several stages of applied axial stress during a total of five loading and unloading cycles. Water pressure in the triaxial vessel was maintained at 2 MPa continuously throughout to ensure that any air entrained in the water would remain in solution. A slight variation in the test scheme from the first series is that flow rate was monitored even during the transient loading and unloading stages. The loading sequence was the same as for the first series, except that more tests were done at additional intermediate stresses, so as to define more accurately the flow rate versus stress relationship.

The DAS enabled simultaneous translation of the data from electrical units to engineering units for all the instruments. Selected instruments such as flow rate sensors, axial load cell, and overall LVDTs were monitored on the CRT screen. The DAS proved most capable in terms of speed of gathering data and the large quantity of data which was stored. Approximately 5,600 data points (each covering 80 channels) were taken over a period of five days. A hard copy of the engineering data is available for data analysis.

On the last day of testing (9 March, 1981), while the axial stress was being increased from 21 MPa to the planned final stress of 28 MPa, the rock failed structurally at a normal stress of 27.5 MPa, in the form of a near vertical split along a major diameter. The failure was unexpected since the rock strength is known to be of the order of 100 MPa. The test program was terminated at this stage. Stress concentration at the specimen ends was apparently responsible for the premature failure of the rock specimen.

To understand the relationship between hydraulic flow and the fracture size in the first series of radial flow tests on the 0.914 m diam specimen, a deterministic model was developed to estimate the critical fracture aperture. However, the regression analysis has not so far been successful in giving a meaningful value for the fracture aperture. Further work is in progress.

For the second series of radial flow tests on the 0.768 m diameter specimen, the preliminary results of unit flow rate versus imposed axial stress are included in Figure 1. The results of the first series of flow tests done on the 9.914 m size are shown for comparison. It is seen that the flow rate has increased considerably for the 0.764 m size. It is suspected that the increase was due mainly to disturbance of the fracture during the complex operation of size-reduction.

As in the first series of flow tests, it was observed that for some of the higher axial stresses, the flow rate was monotonically decreasing with time in an exponential manner, in spite of the new hard plumbing. The LVDT readings also suggested that the fracture aperture was undergoing compressional creep. Figure 2 is a hard copy of the computer drawings of (a), the unit flow rate in liters/min/MPa of differential pressure versus time in minutes, and (b), the overall average compression of the rock specimen over the same period of time. The causative mechanism for the creep could be either (1) plastic deformation of the asperities in contact under sustained normal stress, or (2) dissipation of excess water pressure in the fracture resulting in an increase in effective normal stress, or (3) both. This suggests that actual measurements of water pressures in the fracture plane are vital for understanding the mechanism of flow rate changes in fractures as functions of time. Further analysis of the test data is continuing.

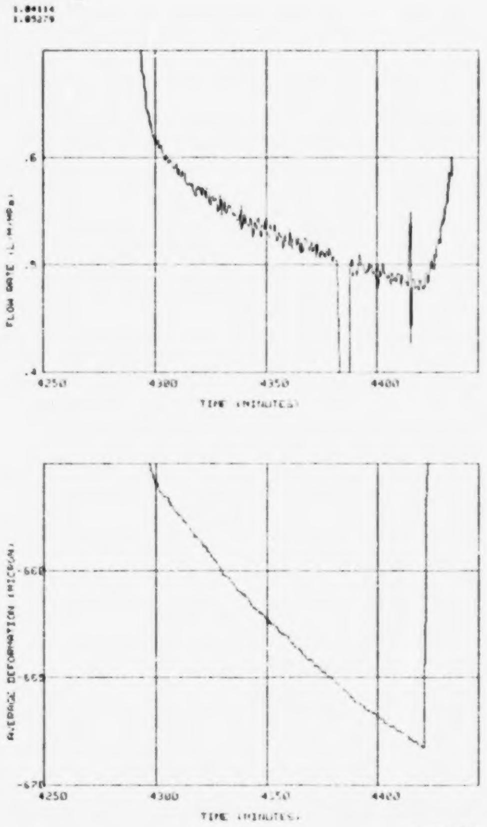


Figure 2. Concomitant Changes in Flow Rate and Axial Deformation--Computer Plot.

In spite of hard plumbing of the hydraulic lines, the flow rate transient persisted, especially for flow tests at higher normal stresses. This transient is tentatively attributed to the time-dependent deformation of the rock fracture itself under sustained loading. This is an important finding and future test programs should consider this phenomenon for time-scheduling.

FUTURE ACTIVITIES

Several phenomenological aspects of coupled stress-hydraulic properties of rough fractures will be studied in detail by creating an artificial fracture in a solid rock core of 1 m diam. The rock properties will first be measured by conducting detailed compression tests on the solid rock before creating an artificial fracture. The opening of this fracture will be carefully monitored during the fracturing process to provide accurate data on the initial aperture. A means will also be devised to measure internal water pressure distribution.

The following activities for the third quarter are tailored to complete investigations of the fracture surfaces in the failed rock and to start investigations on a new piece of solid granite prior to creating an artificial fracture. Analysis of data from the completed two series of tests will continue.

1. Continue analysis of data for the first and second series of flow tests.
2. Open the natural fracture, map the topography, assess the extent of damage, and clean the surfaces of carborundum dust. Before opening the fracture, guide pins will be installed so as to restore the fracture as far as possible to the original condition. The rock specimen will be stored until such time as small cores containing the fracture may be retrieved from the specimen.
3. Perform strength tests on small cores of Charcoal Black Granite, to get an idea of strength and deformability.
4. Make a detailed analysis of the probable causes of failure of the 0.764 m diam specimen.
5. Initiate preparation and instrumentation of an intact Sierra White Granite specimen of 1 m diam for the next series of tests, and begin to study the intact stress-deformation characteristics.

WBS 1.4.8

PROJECT: Stripa Data Analysis

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (T. Chan)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The purpose of the analysis is to gain a better understanding of the response of a fractured granite rock mass to thermomechanical loading. This is to be accomplished by careful comparison of modeled temperature, displacement, and stress fields with measured data from the Stripa heater tests.

The program will attempt to assess the influence of the following factors on the Stripa field data collected during the heater tests conducted at Stripa, Sweden, from June, 1978 to June, 1980: (1) in situ state of stress; (2) presence of excavations; (3) the three-dimensional geometry of the experimental arrangement; (4) temperature, stress and, possibly, loading path dependence of rock properties; (5) presence of fractures; and (6) presence of ground water.

PROGRESS PREVIOUSLY REPORTED

The temperature data base for the full-scale heater experiment was carefully examined for continuity and consistency. Data produced by certain thermocouples over certain periods of time, determined to be of questionable validity, were removed from consideration. In most cases there were documented explanations for the aberrant readings. The remaining data were considered to provide a valid, comprehensive thermal data base.

The bulk thermal conductivity of the fractured granite rock mass was back-calculated using effective medium theory and was not found to differ significantly from that measured with intact rock samples.

The three-dimensional (3-D) nature of thermomechanical stress significantly affects the diametral displacements recorded by the USBM borehole deformation gages, especially those installed in horizontal boreholes, and must be taken into consideration in the data interpretation.

ACTIVITIES DURING THE REPORTING PERIOD

There were two major activities during the reporting period:

1. Detailed examination of selected temperature data in relation to fractures.
2. Finite-element modeling to assess possible influence of the overall Stripa mine excavations on the far-field in situ stress measurements in SBH-4, a deep hole drilled from the surface.

The thermal data study suggests that some thermocouple data which were previously believed to be in error due to corroded thermocouples actually represent real temperature measurements after certain remedial procedures were taken. In particular, some remarkable temperature changes occurred in several thermocouple holes at times coincident with certain hydrology tests in the ventilation drift. Further study of these observations may reveal unexpected evidence of continuous paths for fluid flow between these two drifts at a distance of some 30 to 40 meters.

Finite-element analyses were carried out to model the effect of the overall Stripa mine excavations on the in situ stress measured in SBH-4. Several 2-D models were used. These include (1) two horizontal sections, one at the 360-meter level (closest to SBH-4) and one at the 176-meter level (largest cross-sectional area); and (2) two separate idealizations of a composite of four vertical sections projected onto a plane passing through SBH-4 and normal to the strike of the iron ore body. In these 2-D models, the ore body was assumed to be completely extracted, thereby providing conservative estimates of stress concentration effects.

Overburden weight and horizontal stresses measured by hydrofracturing were assumed as the premining state of stress in the analyses. The resultant stress in the presence of the mine excavations was calculated by the models.

The horizontal models have yielded a stress concentration factor, defined as the ratio of calculated postmining stress to premining stress, within 15 percent of unity at SBH-4. This is illustrated in Figure 1, where contours of the stress concentration factor have been plotted for the east-west stress component in the 360-meter-deep horizontal section. The vertical models are more conservative than the horizontal models in that the mine opening appears closer to the borehole SBH-4 than in the actual 3-D geometry. Nevertheless, over a depth range 50 meters above and below the level (340 meters) of the heater test site, the stress concentration factor given by the vertical models still differs from unity by less than 25 percent. Thus, the perturbation imposed by mining on the in situ stress at the location of SBH-4 is probably less than the scatter of the field stress measurements.

FUTURE ACTIVITIES

Future activities will focus on the following:

1. Numerical modeling of the thermal field around each heater experiment and comparison with the temperature data.
2. Calculation of the state of stress prior to heating in the vicinity of the heater tests.
3. Empirical analysis of displacement data.
4. Development of a rational basis for model enhancement and development.

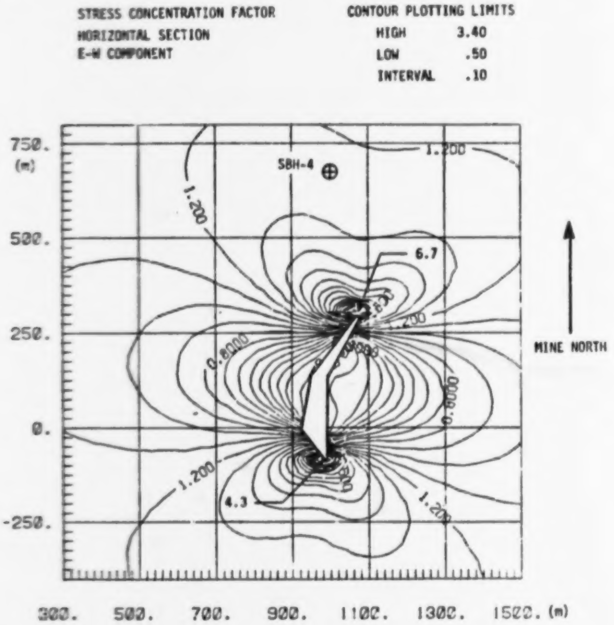


Figure 1. Contour Plot of Excavation-Induced Stress Concentration Factor for E-W Stress Component According to 2-D Finite-Element Analysis (horizontal section at 360-meter depth).

WBS 1.4.8

PROJECT: Material Properties Testing and Analysis

PRINCIPAL INVESTIGATOR: RE/SPEC, Inc.
(A. F. Fossum and G. D. Callahan)

ONWI PROJECT MANAGER: M. R. Wigley

THERMO/MECHANICAL/HYDROLOGICAL ANALYSES
(G. D. Callahan and A. F. Fossum)

OBJECTIVE

The objective of this program is to assess the thermomechanical behavior and constraints of repository situations in representative geologic formations by numerical analysis procedures (involving the canister scale, room scale, and repository scale regions) and by data from appropriate laboratory testing, laboratory bench scale testing, and in situ experiments. The resulting work efforts address and attempt to answer particular problems relative to the Rock Mechanics Program of the NWTS program.

PROGRESS REPORTED PREVIOUSLY

This program was initiated on 1 October, 1978.

Room Scale Investigations

No progress has been reported previously for this task. Work in the code development task was coordinated with this task to create a three-dimensional (3-D) thermoviscoelastic finite-element computer code with a "block solver" capable of solving the large 3-D problems that will be considered in the room scale investigations.

Technical Assistance on Special Repository Problems

Results from the RE/SPEC finite-element code series SPECTROM for comparison with those from the SAI explicit finite-difference code STEALTH were reported for a room scale benchmark problem.

Code Development and Verification

Progress was reported on updates made to SPECTROM 41 to permit explicit definition of transient temperature boundary conditions. A status report was given on the development of SPECTROM 321, a special-purpose three-dimensional thermoviscoelastic finite-element program.

ACTIVITIES DURING THE REPORTING PERIOD

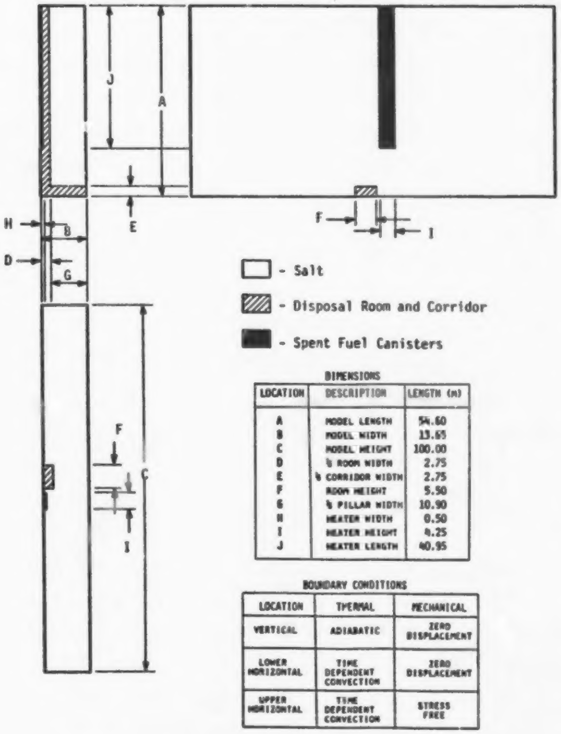
Room Scale Investigations

During this period, the 3-D room scale thermomechanical analysis of a spent fuel repository in salt was initiated. Work concentrated on selecting a conceptual repository, creating a finite-element mesh, and determining an equivalent thermal conductivity for the air in the disposal room, all of which will be implemented in a 3-D analysis.

A spent fuel repository in salt at a depth of 610 m was selected for investigation because this study can then be used as an extension of previous work (Claiborne, Rickertsen, and Graham, 1980), and not merely as an independent study. The length of the simulation will be 50 years, the approximate time required to reach maximum salt temperatures assuming a thermal loading of 14.8 W/m^2 (Claiborne et al, 1980). Ventilation and retrieval of waste may be given secondary consideration, although the procedure in the baseline study will be to emplace 10-year-old spent fuel in an unventilated disposal room and observe the temperatures, displacements, and stresses that develop during the 50 years after emplacement.

The problem geometry and boundary conditions are shown in Figure 1. The room size (5.5 by 5.5 m) has been determined by the Reference Repository Conditions Interface Working Group (RRC-IWG) for the disposal of spent fuel and was used by Claiborne, Rickertsen, and Graham (1980) in analyzing the thermal environments of a spent fuel repository in salt. The extraction ratio (20.15 percent) is slightly higher than optimum for this depth in minimizing room closure (Wagner, 1980); however, it has been used previously (Wagner, 1980), and can be used for comparative purposes. The length of the room used in this analysis is four times the pillar-and-room half-width. The vertical boundaries are assumed to be adiabatic, since they represent lines of symmetry. The horizontal and lower boundaries are given a time-dependent heat transfer coefficient (Wagner, 1980) to simulate an infinite boundary.

Comparisons of room periphery temperatures with this technique are in excellent agreement with temperatures calculated from a conventional extended mesh, while maintaining economic computational costs in light of the 3-D nature of this problem. Mechanical boundary conditions include zero displacement along the lower and vertical boundaries and a traction-free top surface. Initial conditions include a geothermal gradient of 0.035 K/m, with a surface temperature of 15 C. These initial conditions are to be used for 2-D thermal comparisons with Claiborne et al (1980); however, the temperature difference along the height of the finite-element model (100 m) is not significant and should not seriously affect the thermomechanical results of this analysis. A lithostatic initial stress condition is assumed throughout the salt before excavation of the disposal room and connecting corridor. In the mechanical analysis, the spent fuel is modeled as intact salt and the air is assumed to have vitrually no stiffness and no shear strength, i.e., a low modulus of elasticity and a Poisson's ratio of zero. A summary of the material types with their thermal and mechanical properties is given in Table 1.



DIMENSIONS

LOCATION	DESCRIPTION	LENGTH (m)
A	MODEL LENGTH	54.60
B	MODEL WIDTH	13.65
C	MODEL HEIGHT	100.00
D	½ ROOM WIDTH	2.75
E	½ CORRIDOR WIDTH	2.75
F	ROOM HEIGHT	5.50
G	½ PILLAR WIDTH	10.90
H	HEATER WIDTH	0.50
I	HEATER HEIGHT	4.25
J	HEATER LENGTH	40.95

BOUNDARY CONDITIONS

LOCATION	THERMAL	MECHANICAL
VERTICAL	ADIABATIC	ZERO DISPLACEMENT
LOWER HORIZONTAL	TIME DEPENDENT CONVECTION	ZERO DISPLACEMENT
UPPER HORIZONTAL	TIME DEPENDENT CONVECTION	STRESS FREE

Figure 1. Schematic Diagram of the 3-D Finite Element Model.

Table 1. Thermal and Mechanical Properties.

Material	Thermal Conductivity (W/m-K)	Specific Heat (J/kg-K)	Density (kg/m^3)
Salt	4.75[a]	3024.0	2170.0
Air	27.2[b]	1002.6	1.3
Spent Fuel	1.2	3024.0	3000.0

Material	Modulus of Elasticity (MPa)	Poisson's Ratio	Thermal Expansion Coefficient (1/K)
Salt Spent Fuel	13790.[c]	0.4[c]	0.396(10^{-4})[c]
Air	1.0	0.0	0.

[a] Cheverton and Turner, 1971.

[b] The thermal conductivity of air used in this analysis is one thousand times the true conductivity at 36.3 C, the assumed temperature at the repository level. The rationale for the use of this number is discussed later.

[c] Hansen, 1978.

Except for the thermal conductivity of salt, the thermal properties are taken from Claiborne et al (1980). The above thermal conductivity has been used in previous studies (Wagner, 1980) and represents an approximate mean value of Claiborne's temperature-dependent conductivity for salt temperatures from 30 to 100 C.

A finite-element mesh was created that optimized mesh refinement with respect to computer core requirements. A mesh was designed compatible with the in-core storage required by SPECTROM 321 and the necessary refinement in regions of expected severe thermal gradients and high deviatoric stresses. Because of the close spacing of the spent fuel canisters (1.68 m), continuous heat-generating elements are modeled along the length of the room to within a half-pillar width of the intersection. This modeling assumption neglects the thermal gradients in the direction of the row of canisters.

Preliminary development of an explicit-radiative heat transfer routine to accompany the existing heat transfer computer code (SPECTROM 41) has determined an equivalent thermal conductivity for air to account for the combined conduction and radiation across the disposal room. This value was found to be approximately 1,000 times the actual thermal conductivity for this particular problem and will be used in the 3-D thermal analysis. Figure 2 compares roof and floor temperature rises for 30 years following emplacement of the waste for different assumed air thermal conductivities with those found using the radiative routine. In the cases shown, the temperatures compare best with a thermal conductivity of 27.2 W/m-K, although fairly accurate temperatures can be expected for any value between 13.6 and 54.4 W/m-K, since the thermal gradient across the room is reduced considerably using a higher conductivity than the intact rock.

Technical Assistance on Special Repository Problems

The NWTS program calls for the disposal of commercial radioactive waste in a mined geological repository. The decision to emplace spent fuel without reprocessing as well as the possibility of unacceptable operation of a repository have dictated the need for retrievability. Under proposed guidelines, the radioactive waste must be retrievable during the operational phase of the repository.

If retrieval should become desirable or necessary, blast cooling has been proposed as a possible method of rapid drift and formation cooling prior to a retrieval operation. Consequently, a study is currently in progress to determine the feasibility of blast cooling a waste repository in salt. The objectives of this study are to quantify the limitations of this method with regard to the time required to achieve adequate cooling and the effect of thermal shock on the formation stability. Current emphasis is on the thermal analysis.

The heat transfer problem characterized by blast cooling involves the following set of conditions: (1) flow in a rectangular duct with floor heating due to the radioactive waste containers, (2) turbulent flow of the cooling air passing through the room, (3) aerodynamically and thermally developing flow, and (4) surface roughness resulting from the mining process.

The above conditions indicate that a 3-D model may be necessary to achieve the accuracy required to develop an actual cooling scenario. However, initial conceptual studies to determine the feasibility of blast cooling need not reflect the complexity and expense of 3-D modeling.

For initial feasibility studies, the system is being modeled as an axisymmetric room-and-pillar system similar to an infinite cylinder. The cooling flow is considered to be fully developed with the turbulent velocity profile established a priori. The simplified model with smooth walls and no heat generation from the waste canisters will become more complex in subsequent models which are expected to include the effects of wall roughness, internal heat generation, and progressively developing flow.

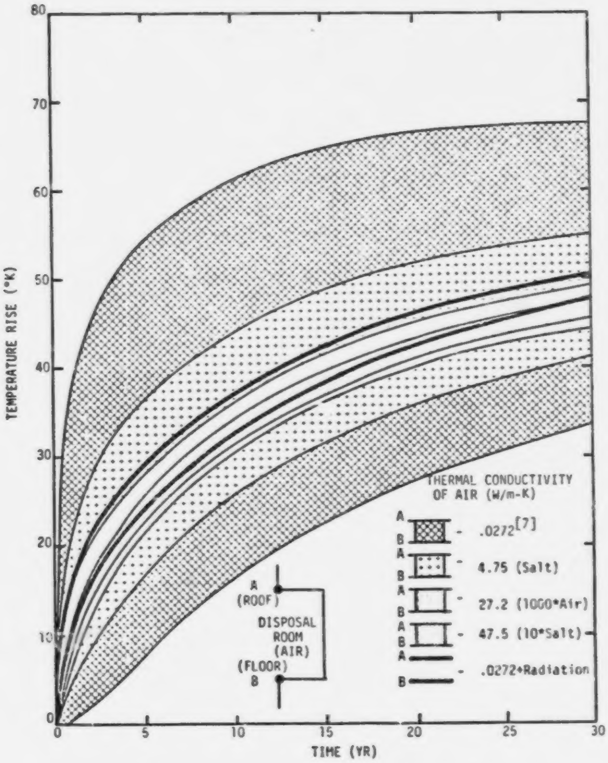


Figure 2. Disposal Room Temperature Rise Variation For Different Thermal Conductivities of Air.

Code Development and Verification

A "block solver" for SPECTROM 321 has been developed. Approximately 90 percent of the computer core storage required for the solution of 3-D problems with conventional finite-element programs is allocated to the in-core storage of the stiffness matrix. Addition of the "block solver" allows formation of the stiffness matrix and solution of the resulting simultaneous equations with only a portion or "block" of the stiffness matrix in core at any given time. The resulting increase in problem size that can be solved in a given amount of available computer core is significant. For typical problem characterized by a bandwidth of 300 and 150 elements, incorporation of the "block solver" allows an increase in the number of finite elements to 1,000, with no increase in required core. Initial computer runs indicate that the increased problem-solving capability is achieved at the expense of execution time and increased computer cost. Comparative solutions of a typical small 3-D problem using the "in-core" versus "block solver" showed an increase in computer cost and time of 15 and 20 percent, respectively. The increase in cost for a more representative analysis involving a geological formation is expected to be greater, but has not been quantified at this time. The code will be used in the room scale investigation during the next reporting period.

The bench scale experimental effort was plagued by a number of difficulties. The data exhibited fluctuations as large as the measurements. Symmetrical deformation of the salt block was not evident from the experimental data. Thus, comparison of predicted results with measured results was nearly impossible.

FUTURE ACTIVITIES

Room Scale Investigations

During the next quarter, the 3-D and comparative 2-D thermal analyses will be completed for the room scale problem. The information obtained will enhance the previous analyses, particularly since Claiborne et al (1980) emphasized canister scale and repository scale thermal investigations. Upon completion of the thermal analyses, the thermomechanical analyses will start. Emphasis in this investigation will be placed on the nonlinear behavior of the salt near the intersection, in both an isothermal and a heated environment. Examination of the room closure, the effective stresses surrounding the room, and the vertical pillar stresses through the first 50 years after emplacement of waste will complement the existing knowledge concerning the safe disposal of nuclear waste.

Technical Assistance on Special Repository Problems

Preliminary verification runs have established the requirement for further modifications to the coupled convective and conductive finite-element program to improve the modeling of the turbulent heat transfer process present in blast cooling. These modifications are currently being implemented, and initial results are expected early next reporting period.

Code Development and Verification

Documentation of SPECTROM 41 will be completed in the next reporting period.

LABORATORY STUDIES

(P. E. Senseny)

OBJECTIVE

The objective of this investigation is to study in the laboratory the constitutive behavior of geologic materials and to formulate constitutive laws that model the thermomechanical response of these materials under conditions expected in a nuclear waste repository.

This program provides constitutive laws that can be used by modelers to predict the stresses and deformations in a nuclear waste repository and to assess the stability of that repository.

PROGRESS REPORTED PREVIOUSLY

Electronic modules were substituted for the mechanical differential pressure gages in the dilatometers in all six creep machines. The dilatometer now controls the confining pressure to about ±35 kPa and gives clean lateral strain-versus-time records.

ACTIVITIES DURING THE REPORTING PERIOD

Specimens that have been allowed to creep along enough to reach steady state had their subgrain size determined as a function of axial stress difference. Figure 3 plots the logarithm of subgrain in microns as a function of the logarithm of axial stress difference in MPa. A least squares fit to the data yields the equation

$$D = 380\ \sigma^{-1.3},$$

where D is the subgrain size in microns and σ is the axial stress difference in MPa.

Three two-stage experiments were performed to assess the influence of stress history on subgrain size. In each experiment, the specimen deformation was allowed to reach steady state before the stress was changed. The experiment was terminated when creep during the second stage of the test reached steady state. All three specimens have been sent out for further analysis.

A test matrix was prepared for the study of the influence on creep of stress history. The test matrix comprises eight tests that address three topics: (1) the influence of time at steady state on creep during a subsequent stage, (2) the influence of stress history on steady-state strain rate, and (3) the influence on creep of stress history beyond the most recent steady-state deformation. Two of these experiments have been completed, and two more are in progress.

Two creep experiments have been initiated at 70 C and low axial stress differences to extend the data base into the low-temperature, low-stress, longer time regime. These tests will be terminated only after substantial steady-state deformation has accumulated in the specimen.

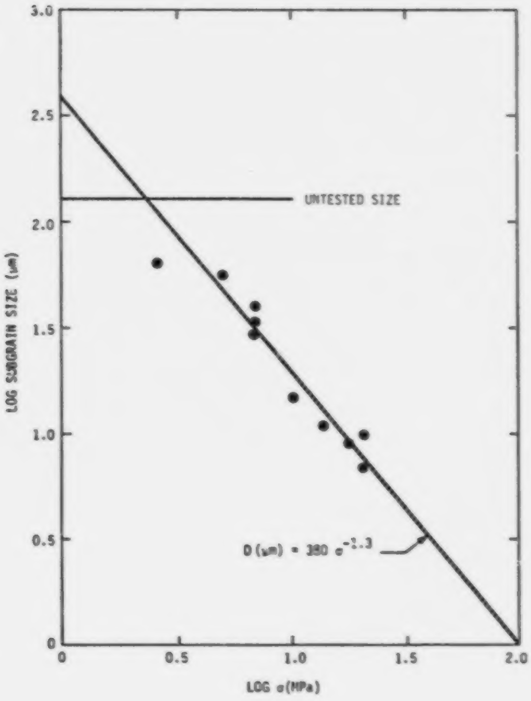


Figure 3. Subgrain Size at Steady State as a Function of Axial Stress Difference for Avery Island Dome Salt.

FUTURE ACTIVITIES

A matrix of tests has been prepared and will be performed on specimens of dome salt from Richton, Mississippi, and Vacherie, Louisiana, and on specimens of bedded salt from the Permian and Paradox Basins. The purpose of these tests is to provide quasistatic strength and creep deformation data that can be used to compare the suitability of these sites to host a nuclear waste repository.

AVERY ISLAND DATA ANALYSES

(R. A. Wagner)

OBJECTIVE

The objective of this task is to perform analytical and numerical evaluations of the field experiments performed at Avery Island, Louisiana. Present and future field experiments may be categorized as follows:

1. Heater
2. Brine migration
3. Accelerated borehole closure
4. Extended gas permeability
5. Fracture healing
6. Heated block
7. Rock mechanics measurements.

The analyses or simulation of these experiments will help assess the in situ thermomechanical properties and evaluate the modeling techniques of situations related to the isolation of radioactive waste.

PROGRESS REPORTED PREVIOUSLY

Before this reporting period, activity was limited to composing a draft report about the numerical simulation of the accelerated borehole field experiment. This numerical simulation was initiated in June, 1980.

ACTIVITIES DURING THE REPORTING PERIOD

The finite-element numerical simulation determined the time-dependent radial displacements along the length of the borehole. The maximum borehole closure occurred at approximately mid-depth, since the thermal and stress conditions are the most severe in this region. The uplift along the mine floor was substantial because of the combined influence of the flatjack pressure and thermal expansion. The results of this a priori simulation will be compared with actual field measurements. Comparison of the numerical and experimental results will help determine the reliability of numerical predictions for analyzing more complex rock mechanics problems related to the disposal of radioactive waste.

A numerical simulation of the Site A heater test at Avery Island was used to analyze the thermomechanical response within the heated region for 500 days. Since the salt's thermal conductivity and creep relation are not known precisely, a parametric study of these two factors was performed. Consequently, six thermal and three thermomechanical cases provided a range of predicted behavior. Agreement between the most representative parametric case and the field-measured temperatures was within 25 percent for most of the modeled region, with the closest agreement occurring along the mid-height of the heater.

Additional thermal analyses are in progress which include refinement of the finite-element model and a more accurate assessment of the thermal conductivity of salt. The results from these analyses will be presented in a report comparing the field measurements with predicted behavior. This study of the Site A heater test will help assess the ability to predict numerically the response from an electrical heater that nearly represents a single waste canister emplaced within an underground salt environment. This approach provides an essential step toward the eventual design of an underground repository for radioactive waste.

FUTURE ACTIVITIES

During the next quarter the Avery Island studies will include continuation of the analyses related to the heater tests. A draft report comparing the numerically predicted and field-measured temperatures, displacements, and stresses at the Site A heater test will be completed. If this comparison is satisfactory, similar simulation and comparison studies will be initiated for the Site B and C heater experiments.

Since not all aspects of the accelerated borehole closure field experiment were addressed initially, a supplementary analysis will consider variations from the proposed field experiment which may include different loading-heating sequences and the addition of crushed salt backfill.

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WBS 1.4.8

PROJECT: Convective Heat Transfer in Room and Pillar Geometries

PRINCIPAL INVESTIGATOR: Ohio State University (R. Christensen)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective is to determine the local and average convective heat transfer coefficients on the surfaces of a repository mine drift, and to measure the local temperature distribution in the drift. These heat transfer coefficients are needed to assess the ventilation and cooling requirements in the repository during waste canister emplacement and retrieval. Ventilation is required to ensure worker safety and may be required to limit the temperatures in both the repository and the waste package.

PROGRESS REPORTED PREVIOUSLY

A basic research effort was started in July, 1979, to determine generalized heat transfer correlations for all interior surfaces of a room, using discrete thermal sources on the floor.

Typical room designs were determined, and the experimental design study developed into a model dynamically scaled to provide hydrodynamic and thermodynamic similarity. The dimensionless parameters that come into play are the Reynolds number, the Prandtl number, room aspect ratios (i.e., length to width, height to width), thermal loading schedule, total thermal load, and surface roughness. The laboratory model was two-dimensional and had a strip heater in the floor (to represent the heat generating waste) and insulated side walls.

Heat transfer coefficients were obtained in the fully developed turbulent region of the channel over a range of Reynolds numbers from 1,600 to 88,700 for two different canister spacings, two heater powers, and various waste loading sequences. These data agree favorably with correlations for mixed convection over the entire range of Reynolds numbers and with forced convection correlations at the highest Reynolds numbers (Re>85,000). These data have been fit via linear regression techniques by the equation:

$$Nu_{\infty}=4.17\ Gr^{0.0137}\ Re^{0.300}.$$

This equation is applicable for $1,000 < Re < 89,700$ and $5 \times 10^6 < Gr < 5 \times 10^7$.

Data have been taken for Reynolds numbers between 9,000 and 89,000 for various heater lengths and for two heater powers.

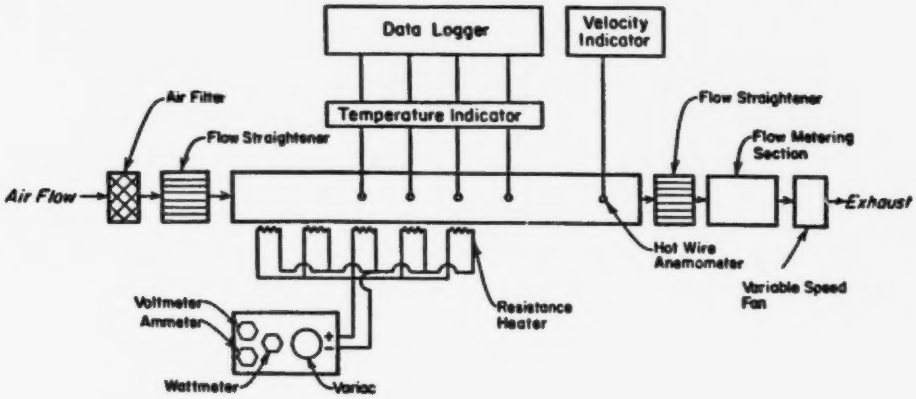

Figure 1. Schematic Diagram of Experimental Apparatus

ACTIVITIES DURING THE REPORTING PERIOD

During the quarter, progress was made in the following areas: analysis of the accumulated data, change in the aspect ratio of the channel, and modification of the flow pattern in the channel.

Analysis of accumulated data for smooth surfaces with a channel height of 9 inches is being carried out by the computer code that determines the convective heat transfer coefficient (h), Nusselt number ($h\ D_h/k_A$), and Grashof number ($g\beta L^3 \Delta T/\nu^2$) as a function of a nondimensional distance (x/D_h). This code has been modified to provide h_{AVE}, Gr_{AVE}, and Nu_{AVE} for the heated length (LH) of the channel. Average heat transfer coefficients, Nusselt numbers, and Grashof numbers have been determined for heating sequences Q through Z with heater power of 5.0 W and 0.5 W and Reynolds number ranging from 9,000 to 89,000. Nu_{AVE} is being plotted versus nondimensional heated length (LH/LT, where LT is the total length of the channel) and Reynolds number. This analysis should result in correlations for average Nusselt number as a function of Reynolds number, Grashof number, and heated length.

The ceiling of the channel has been lowered to 6 inches to determine the effect of aspect ratio on Nusselt number. Lowering the top surface has increased the maximum Reynolds number in the system from approximately 89,000 to 140,000. Data for a nondimensional heated length of 1.0 have been taken at a channel height of 6 inches for Re = 89,000, 63,000 and 32,000. The position of the blower has also been changed; instead of blowing air into the rectangular channel, air is being drawn out of the system (see Figure 1). This new position of the blower has made it possible to reduce vibration significantly. Overall system performance has improved considerably, i.e., there is much less air leakage, less disturbance on flow patterns, and better thermocouple readings. This change also allows an investigation of entrance effects on average Nusselt numbers. Thus, straight in line, right angle, and tee entrances to the channel can be investigated.

FUTURE ACTIVITIES

During the next quarter, data analysis will continue. This will allow formulation of the correlation for average Nusselt number with respect to aspect ratio, heated length, Reynolds number, and Grashof number. Runs will continue for a channel height of 6 inches and an aspect ratio of 1.0.

WBS 1.4.8

PROJECT: Convective Heat Transfer Within Spent Fuel Canisters

PRINCIPAL INVESTIGATOR: University of Delaware (F. A. Kulacki)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective is to provide basic engineering data and correlations for heat transfer from rod bundles typical of spent fuel subassemblies in enclosed canisters. The heat transfer coefficients are to be obtained from laboratory measurements and will be corrected for the effects of thermal radiation. Bundles containing a 5 x 5 rod array and smaller arrays will be considered to provide a basis for a generalized heat transfer correlation. Constant temperature and mixed-type boundary conditions on the canister wall will be used in separate phases of the study.

PROGRESS REPORTED PREVIOUSLY

Previous work on this task included the design, construction, and testing of a vertical circular cylinder (referred to as the "small apparatus") for studies of free convection from a single rod (annulus case) and rod bundles containing four, five, and nine rods. In all cases, the rods are electrically heated with specific power generation scaled to that expected in an actual fuel rod bundle--PWR fuel with 33,000 megawatt day (MWD) burnup, 5 years old. At the end of FY 81, heat transfer results for the annulus case were obtained for the laminar (conduction), transition, and turbulent regimes of free convection.

Two correlations were developed for average heat transfer coefficients, or Nusselt numbers, as a function of Rayleigh number based on gap width and average temperature difference between the walls of the annulus. For the laminar (sometimes referred to as the conduction regime), the correlation is

$$Nu = 1.406\ Ra^{0.077}$$

for $10^3 \le Ra \le 6 \times 10^3$. Heat transfer data for the transition and boundary layer regimes could be combined into one correlation since the measurements did not permit a sharp distinction to be made between the two regimes of convection. The correlation is

$$Nu = 0.163\ Ra^{0.322}$$

for $6 \times 10^3 \le Ra \le 2.4 \times 10^6$.

ACTIVITIES DURING THE REPORTING PERIOD

Preliminary experiments with a 3 x 3 square array rod bundle were conducted during the reporting period, using the following experimental procedure: First, for a given uniform power input to the rods, the temperature distributions on the rods at atmospheric pressure were recorded. Thereafter, the system was evacuated to a pressure of 0.07 mm Hg. With the system "evacuated", power levels to each rod were adjusted to obtain the same mean temperatures on the rods as were observed previously at atmospheric pressure.

Due to symmetry, there are only three characteristic rods in the 3 x 3 rod bundle. The power input to the symmetric rods must be manipulated simultaneously (see Figure 1 for rod numbering). The four outside rods, numbered 1, 3, 7, 9, the four middle rods, numbered 2, 4, 6, 8, and rod 5, were supplied with three different power levels, respectively. Once the mean temperatures on the characteristic rods were the same as those observed at atmospheric pressure, the power to the rods was recorded. The power recorded in vacuum is interpreted as that power

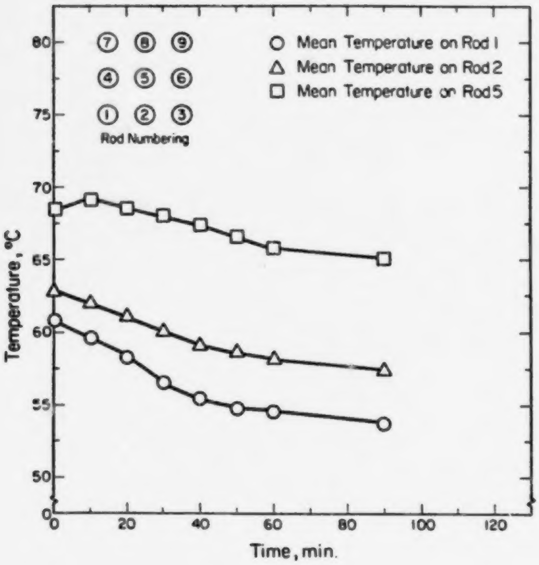

Figure 1. Mean Temperatures on the Characteristic Rods as a Function of Time, Once the Vacuum Pump is Turned off.

Table 1. Results of Experiment to Determine Power Transferred by Radiation Power

Pressure	Power Input to the Characteristic Rods,(a) watts			Mean Temperatures on the Characteristic Rods, C		
	Rod 1	Rod 2	Rod 5	Rod 1	Rod 2	Rod 5
Atmospheric	5.044	5.044	5.044	60.60	62.68	68.60
"Vacuum" 0.07 mm Hg	2.647	2.765	2.110	60.62	62.68	68.61

(a)See Figure 1 for rod numbering.

which is transferred by radiation at atmospheric pressure. The results of one experiment are given in Table 1.

The center rod (rod 5), as expected, experiences the highest temperature, while the outside rods (1, 3, 7, 9) have the lowest temperature. The percentages of heat transfer by radiation for the outside (1, 3, 7, 9), middle (2, 4, 6, 8), and center (5) rods are 52.4 percent and 41.8 percent, respectively. Since the center rod is surrounded by high-temperature rods, while the periphery rods are facing the constant temperature (21 C) outer cylinder, the center rod has the lowest percentage of heat transferred by radiation.

The results of the experiments with the 3 x 3 square array rod bundle are being reduced and will be presented when all experimental data are complete. It is expected that continued analysis of the data will suggest a characteristic length which will properly take into account the geometrical parameters of the system, i.e., the pitch distance, the number of rods in a row, and finally, the diameter of the rod.

In order to investigate the effect of continuous operation of the vacuum pump, the following test was conducted. A steady state with the system evacuated, the vacuum pump was turned off and the mean temperatures on the rods were recorded. The time dependence of the temperatures of the characteristic rods is presented in Figure 1. Once the vacuum pump is turned off, the temperatures on the rods generally decrease. This indicates that the pumping operation does not have a "forced convection" cooling effect on the rods. With the vacuum pump turned off, the density of air inside the cylinder is increased over an extended period of time due to leakage of air into the cylinder. Consequently, the Grashof number is increased, initiating the onset of natural convection heat transfer. Thus, the temperature drops as a function of time. It should be noted that the leak rate is slow enough that it takes 90 minutes for the pressure inside the cylinder to rise from 0.07 mm Hg to 0.7 mm Hg once the pump has been turned off.

Since it appears that forced convection cooling of the rods does not occur, the abovementioned leak rate is acceptable.

FUTURE ACTIVITIES

The instrumentation of the large experimental apparatus will continue. Experiments with the 3 x 3 square array rod bundle will continue during the next quarter. It is expected that more experimental data will help define characteristic length, based on the geometrical parameters of the system.

WBS 1.4.8

PROJECT: The Effects of Far-Field Inhomogeneities on Surface Temperature and Heat Transfer From a Repository

PRINCIPAL INVESTIGATOR: Ohio State University (A. T. Conlisk)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective is to calculate approximate temperature profiles within geologic media that are subject to a spatially finite, time-dependent heat source. Property variations are to be incorporated into the model, and various source (repository) geometries will be considered. The corresponding linear (constant property) solutions will be compared with the nonlinear (variable property) solutions. Where possible, analytical closed-form solutions to the fundamental partial differential equation will be given; in the nonlinear problem, such a solution does not appear possible, and the temperature distribution within the geologic medium will be computed numerically.

PROGRESS REPORTED PREVIOUSLY

The heat balance integral method has been successfully applied to a semi-infinite domain containing planar discontinuities with the heat source (repository) represented by either a planar source or a finite line source. The method has yielded the time history of the temperature distribution within the geologic medium with a minimum of complexity and numerical computation. However, the studies to date do not appear to take into account the nonlinear nature of the problem, although mechanisms for generalizing the method to this case appear to exist.

Work was begun to evaluate the effect of a temperature-dependent conductivity upon the heat transfer from a nuclear waste repository. As an alternative to the heat balance integral method, the problem was formulated as a nonlinear partial differential equation with appropriate boundary conditions. Results for a single slab one-dimensional model problem were calculated, with solutions obtained for both the linear (constant conductivity) and nonlinear (varying conductivity) problems and a comparison made of the calculations for granite in each case. The results tended to confirm that varying conductivity can have a significant effect upon the temperature distribution within the repository.

ACTIVITIES DURING THE REPORTING PERIOD

Introduction

Both experimental and analytical problems were investigated. During the early part of the quarter an experimental apparatus, believed to model many of the features of an actual nuclear waste repository, was put on line. Measurements of the temperature distribution within the repository were begun.

On the analytical side, work progressed in two areas. Dimensional results were obtained for the dimensionless model problem which was presented previously. In addition, a two-layer problem, which is more representative of actual repository geometries, has been formulated. The geometry of this problem is similar to that of the experimental apparatus. Thus, the analytical results may be easily compared with the appropriate experimental data.

Experimental Apparatus

The experimental apparatus consists of a heating strip placed at the interface of two materials. The geometry corresponds to the case of a finite slab above a semi-infinite body. A constant temperature bath maintained a constant temperature boundary condition at the top of the overlying slab. A salt repository overlain by shale was selected as the representative host medium for the actual two-layer problem, and a survey of commonly available materials with similar thermal properties was made. As a result, a 1 1/2 in. plexiglas slab was placed on top of a gypsum plaster block for the model apparatus. The heating strip is located between the plexiglas and the gypsum, and the repository itself is 2 ft square. The heating strip is 2 in. wide by 12 in. long. A sketch of the repository is depicted in Figure 1.

The configuration corresponds to a two-dimensional thermal field with a finite rectangular heat source. Consequently, thermocouples were placed at the locations depicted in Figure 1. This grid pattern was chosen such that knowledge of the temperatures of functions of location and time would sufficiently reflect the thermal behavior of the configuration. Type T thermocouples were used, and a computer program tabulated data and plotted temperature versus time at specified thermocouple locations.

Measurements Procedure

At the beginning of each test sequence, thermal equilibrium is required. At this stage 50 W of power was applied at the heating strip until the temperature at thermocouple 109 of Figure 1 reached 250 F (generally power was applied for about 30 min). At this point, the power was shut off and the model allowed to cool. The temperatures within the repository at all thermocouple locations were monitored. While the power was applied and for an equal length of time after it was shut off, the temperatures were recorded every 2 min. While the block was cooling, the time interval between data points increased as the rate of cooling decreased. At the conclusion of each test, the data were reduced by computer, resulting in the data being presented in graphical and tabular form. Temperatures were usually recorded for about 20 hr. Tests were run with and without insulated boundary conditions at the gypsum-ambient interface. Little difference in the measured temperatures at selected locations was found. These results tend to indicate that the plexiglas-gypsum model may be considered a semi-infinite body.

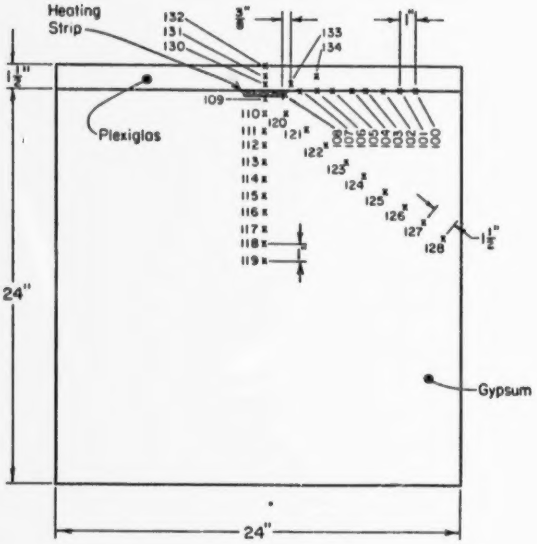

Figure 1. Scaled Model Repository (thermocouple positions are indicated).

Experimental Results and Conclusions

Seven different tests were run with the plexiglas-gypsum model corresponding to different power step inputs (50, 25, 10 W for 30 min) and power applied to maintain constant temperature at thermocouple 109 for 1 hr (240, 180, and 100 F). Six tests were conducted with uninsulated repository-ambient boundaries. A seventh test for an insulated repository-ambient boundary was also completed for step power input of 50 W applied for 30 min.

A typical set of results at selected thermocouple locations for a power step input of 50 W for the uninsulated boundary case is presented in Figures 2a and b. Consider first Figure 2a:

Thermocouple 109 corresponds to a position directly underneath the heating strip. Heat was applied until the temperature at that location reached 250 F. The temperature appears to rise exponentially to 250 F, at which point the power is shut off and the strip proceeds to cool to the ambient.

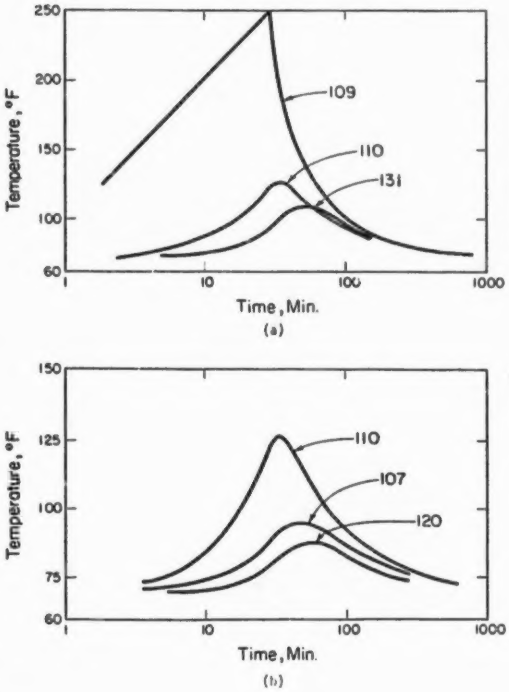

Figure 2. Temperature Histories at Selected Locations Within the Plexiglas and Gypsum (thermocouple numbers are indicated).

indicated).

To illustrate the asymmetry of the model in the vertical direction, the temperatures at thermocouples 110 and 131, which are at equal distances above and below the heating strip, are also shown. Due to the higher conductivity of the gypsum (0.48 W/m C vs 0.209 W/m C for the plexiglas), the effect of the heating is felt almost instantaneously at thermocouple 110, which achieves a higher temperature than the corresponding point in the plexiglas.

To illustrate the directional property of the heat flow from the source, the temperature history at thermocouple 110 is replotted in Figure 2b, along with the corresponding curves at thermocouples 107 and 120. Thermocouple 110 appears to experience a greater heat load than thermocouple 107; it is evident that heat is conducted preferentially in the vertical direction. Thus, the system appears to be working as planned. Comparisons between the data and the heat transfer codes being developed by this task will be made as the codes become available.

Analytical Activity

Analytical work during the quarter was concentrated in two areas. First, the dimensionless model problem which was formulated previously has been dimensionalized, and some results for salt at given initial loading have been obtained. In an attempt to bound the temperature rise at the repository location, numerical experiments were performed. First, two linear constant conductivity cases were run corresponding to the lowest and highest thermal conductivities expected to exist within a typical repository. These two curves should give lower and upper bounds upon the temperature rise at the source plane and, to check the hypothesis, the nonlinear case was run for the salt parameters. It was found that the nonlinear curve was bounded by the two linear curves. However, other calculations for different values of the initial loading are required before detailed conclusions can be drawn.

Second, a two-layer one-dimensional problem was formulated and a linear solution was deduced. The fraction of heat which passes below the source plane is a function of time and can be found by requiring continuity of temperature at the source plane as it is approached from above and below. Formal results are as yet unavailable.

FUTURE ACTIVITIES

During the next quarter, work will continue in an effort to improve the experimental apparatus. A new repository model is being built to incorporate the inclusion geometry. Analytically, the two-layer model will be coded for computation on the computer and the results for the linear and nonlinear problems compared. In addition, the experimental and analytical results will be compared to ascertain the validity of the analytic model.

Also, during the next quarter, a two-dimensional problem will be formulated for the case where a foreign inclusion is present in the geologic media.

WBS 1.4.8

PROJECT: Development of ROCMAS (Thermo-Mechanical-Hydrological) Code

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (C. F. Tsang and J.S.Y. Wang)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The objectives of this project are to develop a model simulating thermo-hydro-mechanical flow in fractured rock masses and to monitor the state of the art in modeling of fractured systems. This modeling capability is needed to predict the effects of waste heat and to assess the movements of ground water and possible radionuclides between the repository and the biosphere.

PROGRESS REPORTED PREVIOUSLY

Work in the first quarter of FY 81 covered two main areas: development and documentation of the ROCMAS code and preparation of a review paper to generalize the state of the art in modeling.

In the area of the ROCMAS code, the focus was on applying the code to the case of fluid injection into a deep-lying horizontal aquifer (a well test geometry). The simulation demonstrated the importance of coupling between rock stress and fluid flow.

ACTIVITIES DURING THE REPORTING PERIOD

The development of the thermo-mechanical-hydrological fractured rock code continued, and the preparation of the review paper on the status of modeling was completed.

A new coding for thermally induced hydromechanical calculations was implemented. This replaced the former arrangement of using the DOT code externally coupled to the ROCMAS code. In the new version, thermal conduction is solved by ROCMAS directly and coupled back for hydromechanical analysis.

As a validation of ROCMAS, a simulation of the thermally induced fluid flow velocity on a thermal front was made. The density difference between the hot fluid on one side of the front and the cold fluid on the other side induces a mixing movement. The instantaneous flow velocities along the sharp front were compared with analytic solutions. This test of the code showed that results are sensitive to the sizes of the finite-element grids used in the simulation.

The draft, Status of Modeling Flow and Transport in Fractured Rock Masses as Related to Radioactive Waste Isolation, was sent to ONWI for review. The paper discusses the governing equations of fluid flow, rock deformation, heat transport, and solute transport; the numerical methods of finite differences, integrated finite difference, and finite element; and applications in well testing analyses, mined cavern tests, and regional basin studies in fractured rock formations.

Applications of the code ROCMAS are reported as part of the paper entitled New Approaches to Problems of Fluid Flow in Fractured Rock Masses.

FUTURE ACTIVITIES

The development, validation, and application of the thermally induced coupled hydromechanical code will continue.

WBS 1.4.8

PROJECT: Boundary Element Model Development--Repository Design Studies

PRINCIPAL INVESTIGATOR: University of Minnesota (A. M. Starfield)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

There are two major objectives of this work. The first is to develop and apply boundary-element computer models for thermomechanical analyses of repositories in bedded salt. The second is to develop constitutive models for the inelastic, time-dependent behavior of salt through laboratory investigation of its response under varying loading conditions.

PROGRESS REPORTED PREVIOUSLY

Initiated in June, 1976, this program has resulted in several boundary-element computer codes. These codes, which include SALT3, SALT4, THERMO, JUDITH, EXPAREA, and SALTY, have been completed and documented to the extent they are presently available for design studies of far-field effects of an underground repository in salt. In March, 1980, the program was expanded to include a combined laboratory and constitutive model investigation. A special laboratory facility was constructed for this work.

The benchmark study using SALTY was suspended pending completion of RE/SPEC's finite-element study. Also, problems with the three-dimensional code, REPOS, were resolved, and the code was nearing completion. Work continued on code development, testing the behavior of Taylor kernels, and other expressions for improved analyses. Further, the fabrication of the laboratory was also nearing completion.

ACTIVITIES DURING THE REPORTING PERIOD

Design Studies

The sensitivity analysis of key input parameters for the SALTY code has been completed. Its purpose was to identify those parameters which have significant control of the thermomechanical behavior of repository conditions. For surface displacement, the depth of the repository was the most significant factor, whereas for room closure, the primary parameters were extraction ratio, depth, thermal loading, thermal conductivity, and the coefficient of thermal expansion.

Work on the code REPOS has been completed, and final documentation is under way. Delays in this work were due to code revisions to the creep equation and the coding of off-seam stress and displacement computations. The REPOS code, a three-dimensional boundary-element code, will facilitate economic far-field analyses of repositories. Such analyses are at present prohibitively expensive using either three-dimensional finite-element or finite-difference computer codes.

Code Development

Work on the development of analytical solutions for heat sources in transversely isotropic materials and also for displacement discontinuity kernels in layered materials has been completed in the sense that the analysis has been taken as far as possible. Both these avenues of research have, however, been disappointing and have not led to results that can realistically be implemented in any of the codes.

Development of a first-generation, coupled, finite-element boundary-element code has been completed. The solution procedure exploits linear isoparametric boundary elements and finite elements, and it currently models linear isotropic elastic material behavior. Plane strain conditions are assumed. Heat sources and thermal stresses have not yet been introduced into the model. Testing of the code has shown satisfactory agreement between finite-element, boundary-element solutions to selected problems and independent solutions to these problems.

The following developments of the code are either in progress or planned for the next quarter:

- Introduction of quadratic isoparametric elements for both boundary-element and finite-element domains
- Enhancement of the solution procedure to include complete plane strain conditions (this is required for adequate handling of plasticity and other nonlinear problems)
- Changes in a matrix inversion routine to achieve greater computational efficiency
- Introduction of an automatic node generation routine.

Laboratory Investigations

Assembly of the laboratory is almost complete. Upon the completion of this subtask, work will progress to the phase of the test program which focuses on the memory aspects of salt creep response.

FUTURE ACTIVITIES

As of 2 March, 1981, the contract tasks and scope have changed. Revised objectives will be presented next quarter.

WBS 1.4.8

PROJECT: ONWI Support Program: Effects of Water in Salt Repositories

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (C. F. Baes, Jr.)

ONWI PROJECT MANAGER: J. F. Kircher

OBJECTIVE

The objective of this program is to predict from experimental and modeling studies those consequences of the presence or the ingress of water to a salt repository that might compromise the integrity of the repository.

PROGRESS REPORTED PREVIOUSLY

Following initial studies of salt deposition onto beds of salt crystals from flowing brine in a negative temperature gradient, studies of the isothermal consolidation of salt beds under uniaxial stress in flowing brine were begun. The initial results, obtained in a 1.27-cm-ID column, gave evidence of a wall effect, i.e., the void fraction was found to increase with distance from the (top) end of the column where the stress was applied. Consequently, a larger (2.54-cm-ID) column was built for subsequent measurements. These indicated that, while the wall effect was still present, it was considerably reduced. The results from these runs (for average particle size from 0.012 to 0.035 cm and applied uniaxial stresses to 155 bars) could be represented by the three-parameter equation, $\phi(t) = a - b \ln (c + t)$, in which ϕ is the void fraction and t is the time. A generalized treatment of these data was adapted from one by Coble (1961) for the sintering of metal and ceramic powders, and led to an equation which was shown to be equivalent to the above three-parameter equation.

An apparatus was built to measure the permeability of a single grain boundary between two salt crystals under stress. A number of runs were completed, and most of the results were placed in a computer-readable form.

An apparatus was designed and built to study brine migration and permeability in 10-cm-diam by 10-cm-long halite core and consolidated salt specimens subjected to axial pressures up to 150 bars and temperature gradients up to 2 C/cm.

ACTIVITIES DURING THE REPORTING PERIOD

Salt Consolidation

During the reporting period, a draft of a paper titled The Consolidation and Permeability of Salt in Brine was prepared and submitted to ONWI for approval. The following is drawn from the summary and conclusions section of the report.

Beds of salt crystals in brine and other fluids subjected to a constant applied stress were found to consolidate in an approximately linear fashion with the logarithm of time. The rate increased with the increasing stress and decreased with increasing particle size. The decrease of the void fraction with time could usually be described almost within experimental error by a simple three-parameter equation. This could be transformed into one suggested by Coble (1961) to describe the kinetics of sintering in terms of the initial average particle size, a rate constant for the loss of void volume, and a rate constant for the growth of the average particle size.

A substantial wall effect was indicated by an observed increase of the void fraction with distance from the top of the consolidating column where the stress was applied and by the observation that shorter columns consolidated faster than taller ones of the same diameter. This effect was represented by an exponential decrease in the local stress with distance from the top of the column expressed as the weight of intervening salt. This correction for the wall effect, along with assumed linear dependencies of initial void fraction and the rate constant for loss of void volume on the local stress, gave a general expression which could be fitted to all the consolidation data in NaCl brine.

When large amounts of $MgCl_2$ were present in the brine, the rate of consolidation was greatly reduced, less even than that for undried salt in dodecane. Dried salt in air showed the lowest consolidation rate, suggesting that mechanical deformation is not an important mechanism in consolidation.

The permeability of columns of salt was found to decrease with the second power of the initial particle size, as expected from the Blake-Kozeny equation; but as consolidation proceeded the permeability decreased with the sixth power of the void fraction, much more rapidly than would be expected from the Blake-Kozeny correlation.

Several important implications may be drawn from these studies regarding the suitability of bedded halite as a storage medium for radioactive waste. Perhaps most important are (1) the rapidity with which consolidation can take place, and (2) the low permeabilities which can result. Thus, from the general expression fitted to the data in NaCl brine, at a lithostatic stress of about 100 bars and a temperature of 30 C, the void fraction, ϕ, should be given by

$$\phi(t) - \phi(0) - 0.04 \ln [1 + 0.3\, t/z(0)^3],$$

where t is in years and z(0), the initial particle size, is in cm. Extrapolation of this expression to larger crystals and longer times, suggests that a medium of 1 cm crystals would consolidate and lose its permeability to flowing brine about as follows:

Time, yr	Void Fraction	Pm, Darcy
0	0.37	86,000
10	0.31	30,000
100	0.23	5,000
1,000	0.14	250
10,000	0.05	0.5
27,000	0.01	3×10^{-5}
34,000	0.00	-

If the initial size of the crystals were reduced to 1 mm, these times would be reduced a thousandfold, i.e., consolidation would be complete in about 35 years. The permeability at a given void fraction would be reduced by a factor of 100 and at 27 years would have fallen to 0.3 μ Darcy. Thus, the self-sealing properties of bedded salt which originally attracted attention to this material as a storage medium are supported by the present measurements.

Permeability of Single Salt Grain Boundaries to Brine

Additional sets of permeation data have been collected at axial crystal loadings of 27, 38, 62, 93, and 120 bars at 20 C. During this period, data collection was converted to a continuous computer-controlled input of time, temperature, and effluent weights. Data fitting has been completed for all but the most recent work according to the procedure previously outlined.

Salt Core Brine Migration Experiment

Experimental work was started in the salt core brine migration apparatus. A salt cylinder was prepared by the consolidation of 250 to 420 μm salt crystals in brine under a pressure of 150 bars. A helium gas sweep was started to carry away moisture, leaving the upper and lower surfaces of the salt cylinder following the removal of gross brine.

FUTURE ACTIVITIES

Following approval, the report on salt consolidation and permeability will be submitted for publication.

Analytical efforts will continue to derive a model for the dependence of single crystal permeability on time and applied stress. Permeation data at elevated temperatures will be collected, and the effects of crystal interface contamination will be explored.

Efforts to measure the migration of brine through various salt-brine configurations under stress and in a temperature gradient will continue.

REFERENCE

Coble, R. L., 1961. "Sintering Crystalline Solids. I. Intermediate and Final State Diffusion Models", Journal of Applied Physics, Vol. 32, No. 5, pp. 787-792.

WBS 1.4.8

PROJECT: Analysis of Thermal/Mechanical/ Hydrological Response of Rock

PRINCIPAL INVESTIGATOR: Science Applications, Inc. (R. Hofmann)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The objectives of this study are: (1) to further develop and verify special-purpose versions of the computer code system STEALTH, which will be used to aid in the design and licensing of a nuclear waste repository; (2) to document this development, verification, and use of the STEALTH computer code system as it applies to geologic isolation of nuclear wastes; and (3) to perform generic design studies that will form the design and licensing data base for site-specific analyses.

PROGRESS REPORTED PREVIOUSLY

The project was started 1 October, 1980, with five initial tasks:

1. Gather a set of meaningful analytic comparison tests and perform four cases using STEALTH
2. Perform one code-to-code comparison test comparing a STEALTH code to a SPECTROM code
3. Perform one bench-scale comparison test using data generated by the South Dakota School of Mines (SDSM)
4. Complete the Project Salt Vault (PSV) and Stripa simulations using the best available constitutive data
5. Establish a quality assurance basis for ONWI's use of the STEALTH code system.

The main thrust of the work in the first quarter of FY 81 was to establish the quality assurance basis for the various simulations that will be performed. The steps taken to reach this goal include (1) rerunning previous simulations on a PRIME 750 computer to verify hardware independence of the STEALTH codes, (2) writing a Quality Assurance Plan (QAP) which will govern ONWI-specific STEALTH developments, and (3) creating a base set of STEALTH files for use in future calculations.

So far, the steps to achieve these goals have been accomplished with minimal difficulty. Old PSV and Stripa runs have been successfully rerun, using current STEALTH files, version 3-21. Also, ONWI-specific STEALTH updates have been converted to the ATLAS program maintenance system.

ACTIVITIES DURING THE REPORTING PERIOD

Current activities have concentrated on completing PSV and Stripa simulations. In particular, an asymmetric simulation of PSV and axisymmetric simulations of Stripa using the best available salt and granite constitutive data, respectively, have been completed. The results of these calculations are being reduced and reviewed in preparation for writing topical reports.

Also during the past quarter, work was begun on building a library of analytic test cases. The list of candidate problems is being compiled for ONWI review so that four problems can be chosen for computation by STEALTH.

It has been determined that the SDSM uniaxial experiment is inappropriate for use as a laboratory-scale simulation test. A replacement task has been under discussion, but so far is not defined.

FUTURE ACTIVITIES

Three main milestones are anticipated in the next quarter:

1. Completion of data reduction from the PSV and Stripa simulations.
2. Beginning of a STEALTH-SPECTROM repository-scale, code-to-code comparison.
3. Definition of the SDSM replacement task.

WBS 1.4.8

PROJECT: Analysis of Flow Through Fractured Crystalline Rock

PRINCIPAL INVESTIGATOR: University of Waterloo (J. E. Gale)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

This project has two tasks, the Stripa fracture hydrology data analysis and the permeability size effect study. The objectives of the Stripa analysis are (1) to characterize the rock mass fracture parameters by (a) using standard rock engineering approaches to characterize the rock mass and (b) completing a thorough statistical analysis of the fracture data, (2) to undertake a thorough assessment of the physical hydrogeologic characteristics of the Stripa site using the available borehole packer test data, and (3) to analyze an existing series of laboratory and field pressure pulse tests.

The objective of the permeability study is to determine, from laboratory studies, an empirical size-effect relationship between fracture permeability and the size of the fracture plane being tested in an attempt to determine the relationship between laboratory and field results. This project will (1) ensure continuity between the field data collection and the interpretation of the fracture hydrology data from Stripa, and (2) result in a well-documented data base being subjected to a thorough, systematic analysis. The two tasks combined will assist ONWI's NWTS program fracture hydrology investigation by contributing to the procedures and methodologies required to evaluate flow through fractured rock masses.

PROGRESS REPORTED PREVIOUSLY

This project started on 13 March, 1981. Therefore, this is the first quarterly technical progress report.

ACTIVITIES DURING THE REPORTING PERIOD

Stripa Fracture Hydrology Data Analysis

Characterization of Rock Mass Fracture Parameters. Progress has been achieved in (a) calculating the true strikes and dips of the fractures in the drill core (30 percent), using the raw fracture data and the borehole survey coordinates, (b) calculating RQD (rock quality determination) values from the drill core data (50 percent), (c) evaluating fracture sets using a cluster analysis program (20 percent), and (d) initial work in analyzing the fracture data collected from the recent mapping in the ventilation drift.

Assessment of the Physical Hydrogeologic Characteristics of the Stripa Site. The basic equations governing flow through fractured media are being reviewed. Decisions resulting from this review will enable the final revisions to be made to the data analysis codes and the actual data processing and interpretation to proceed. The initial analysis of the injection test data using porous media and the equivalent single-fracture concept is practically complete.

Permeability Size Effect Study

The complete set of samples has been collected. The engineering test plan has been finalized. All equipment components are in place, and the actual testing program will be initiated in April.

FUTURE ACTIVITIES

In the next quarter the calculation of the orientations of the fractures intersecting the drill core should be completed. This will enable completion of the analysis of the fracture orientation data from Stripa, including a detailed analysis of any clusters in the data. Also, the basic statistical analysis of the fracture trace lengths and fracture spacings will have been completed, providing the basis for a detailed analysis, in the third quarter, of the degree of fracture interconnection within the rock mass. It is expected that the analysis of the drill core data using standard rock engineering approaches will have been completed by late June.

The initial analysis of the injection test data using porous media and equivalent single-fracture concepts will be completed, and these results will be included in the SAC fracture hydrology data report. Detailed analysis of the injection test data should be well under way during the next quarter. Next quarter activities will also include completion of the analysis of the laboratory pressure pulse tests and stress-permeability testing of four to five of the rock cores containing natural fractures.

SUMMARY

1.5 REGULATORY AND INSTITUTIONAL

Work conducted under this program element includes the development of licensing strategies, criteria, and guides necessary to identify the required information for, and the preparation of licensing documents.

Work in the second quarter of FY 81 included review of draft regulations, a Licensing-Interface Control Group (L-ICG) meeting, preparation of Licensing Topical Reports (LTRs), and participation in NRC confidence rulemaking activities.

A DOE/NWTS briefing for the NRC in Silver Spring, Maryland on February 12 to discuss the NWTS Waste Package program was held. Preliminary plans for future meetings were discussed in some detail. Licensing Program Office (LPO) representatives participated in the ANS Waste Management '81 workshop in Tucson on February 23-26. LPO attended a Nevada Nuclear Waste Storage Investigations (NNWSI) site visit and briefing for the NRC on February 17-20. The visit, coordinated by NNWSI personnel, was intended to familiarize NRC with the scope and progress of NNWSI activities. The LPO manager participated in the BWIP and NNWSI midyear reviews during the week of March 19. The 10 CFR 60 procedural rule was issued as a final regulation during the report period.

The third Licensing-ICG meeting was held in Columbus on January 28-29. ICG members' comments on the draft Licensing Plan were reviewed and incorporated. The members were briefed on the status of the Licensing Project Manager (LPM) procurement. Two LTRs, Thermal Effects and Scenario Development were selected for recommendation to DOE as the next two reports to be prepared.

Work continued throughout the report period on the six LTRs now under preparation. LTR preparation activities included development of detailed outlines and working sessions to provide draft input. Arrangements were made to actively involve representatives of NNWSI and BWIP in the preparation of LTRs. Intensive efforts continued to revise the Preliminary Information Report to include DOE comments, with working sessions held at both subcontractor offices and at ONWI. Working groups were established to address specific areas, and a letter was forwarded to DOE providing the plan for addressing comments. The final draft of the PIR was essentially complete by the end of the report period, with only editorial revisions remaining to be completed early in the third quarter. It was recommended to DOE that the PIR be published as an ONWI document. The second draft of the NWTS Safety Assessment plan was reviewed in-house, and revisions are under way.

A draft summary, prepared by NRC, of the participants' positions in the confidence rulemaking was reviewed at the request of DOE. Comments were provided to the DOE, and LPO representatives participated in preparing the final response to NRC for submittal in early April.

Proposals from candidate LPM groups were received and evaluated by the Site Selection Board. Initial screening was completed, and site visits were conducted during the report period.

A draft BWIP Technical Criteria Document (RSD-BWI-TI-005) was reviewed. Two environmental assessments prepared by BWIP to cover exploratory activities at the Hanford site were reviewed, and the resulting comments were discussed at a meeting at DOE-HQ with representatives of BWIP, LPO, and DOE.

Several drafts of the 10 CFR 60 technical criteria were reviewed. A proposed strategy for NRC interactions, including 10 CFR 60 issue resolution procedures and a proposed meeting agenda, were forwarded to DOE.

Work continued at the Battelle Human Affairs Research Centers (HARC) to build on previous social and institutional analyses to help ONWI better address nontechnical concerns in its program planning activities. Internal working-draft reports were submitted on state, local, interest group, and citizen involvement in repository site selection and characterization and on negotiation of consultation agreements.

Meetings were held January 19 to 23 with consultants and local and state officials in Mississippi and Louisiana. It was indicated that Mississippi is proposing to do parallel studies with state technical people similar to some of the work DOE contractors will be doing in the location phase. Primary emphasis will be on hydrology studies. It was also indicated that a joint executive/legislative committee on nuclear waste for Louisiana will be established.

SUMMARY

1.6 TEST FACILITIES AND EXCAVATIONS

The scope of the test facilities and excavations task covers the acquisition, design, construction and development, and operation and maintenance of required field test facilities and excavations. The primary objective of this task is to provide the proper field testing facilities to support the field test activities of the nuclear waste isolation program.

All major facilities and systems designs for a salt test facility conceptual design project were developed during this quarter. Also, the QA plan for the conceptual design and the Title I QA plan were submitted to ONWI for review and comment.

The main activity this quarter of the Alternate Geology Test Facility--Mine Screen studies was review of the files from two computerized data bases on existing mines, CRIB and MAS. It was concluded that CRIB is not as useful for this study as first thought, and efforts have been concentrated on working with MAS.

WBS 1.6.1

PROJECT: Salt Test Facility Conceptual Design

PRINCIPAL INVESTIGATOR: Stearns-Roger Services Inc. (J. C. Mattern)

ONWI PROJECT MANAGER: T. M. Solack

OBJECTIVE

The objectives of this project are to:

- Develop a conceptual design for a salt test facility in a dome salt formation or a bedded salt formation
- Prepare cost estimates for the detailed engineering, construction, and decommissioning of the facility
- Prepare an environmental assessment for the facility
- Develop a Quality Assurance Plan for the Title I phase.

The specific locations for the facility are not identified. Experimental test requirements will be defined by ONWI and the Westinghouse Advanced Energy Systems Division.

PROGRESS REPORTED PREVIOUSLY

This project began in November, 1980.

A draft of the Final Design Criteria was submitted to ONWI for comment.

ACTIVITIES DURING THE REPORTING PERIOD

All major facilities and systems designs were developed during the reporting period. An artist's cut-away view of the Salt Test Facility is presented in Figure 1. The QA Plan for the conceptual design and the Title I QA plan were submitted to ONWI for review and comment.

A draft of the Environmental Assessment (EA) was submitted to ONWI for comment. The EA is being revised, based upon the comments received.

One meeting was held to discuss project progress and geotechnical issues. The second meeting was the 50 percent design review meeting held at the Stearns-Roger's offices in Denver, Colorado. A report concerning the cost estimate for the Salt Test Facility conceptual design was prepared as part of the 50 percent design review.

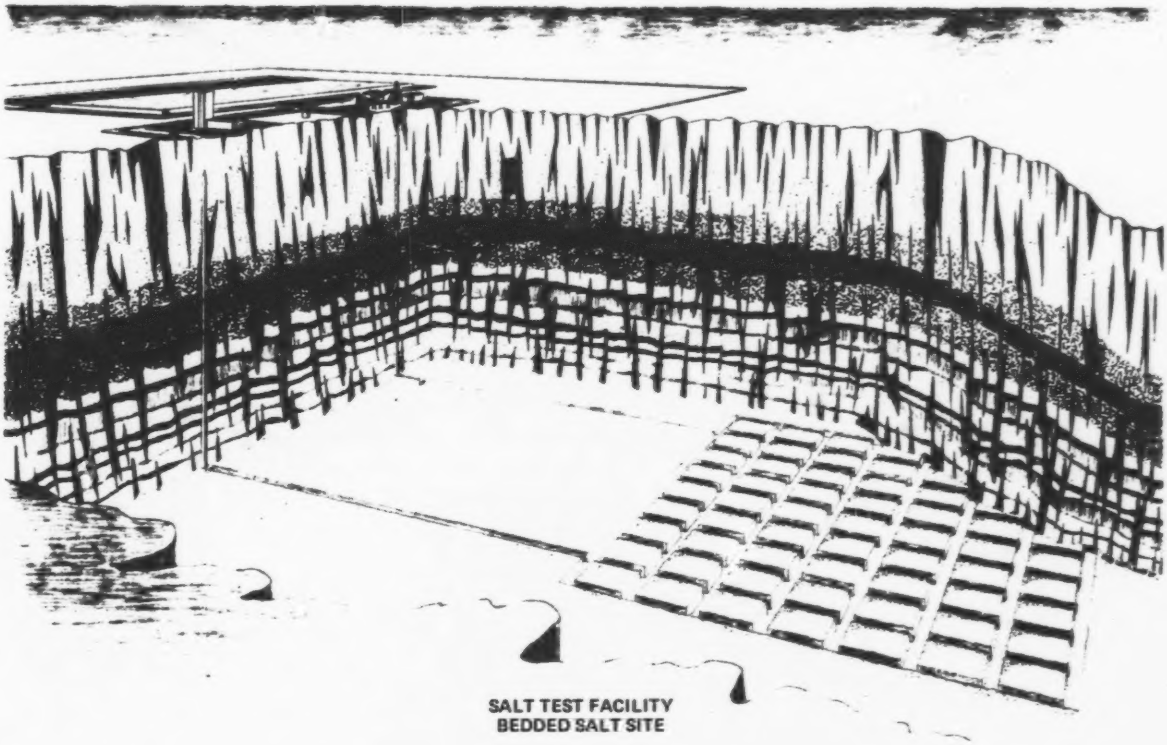
SALT TEST FACILITY
BEDDED SALT SITE

Figure 1. Artist's Conception of Cut-Away View of the Salt Test Facility.

WBS 1.6.2

PROJECT: Alternate Geology Test Facility--Mine Screen

PRINCIPAL INVESTIGATOR: Pincock, Allen & Holt, Inc. (J. R. Swaisgood)

ONWI PROJECT MANAGER: M. W. Anthony

OBJECTIVE

The principal purpose of this project is to identify suitable candidate sites for an Alternate Geology Test Facility (AGTF) in geologic media other than salt. Specific objectives include: (1) compiling a list or data bank of existing underground openings in suitable rock types which meet general identification criteria; and (2) developing a computer program to evaluate and compare candidate sites in granitic rocks using site-specific criteria to identify those sites with sufficient potential to warrant further investigation. The project will be performed using publicly available information only.

PROGRESS REPORTED PREVIOUSLY

The project was authorized on 12 November, 1980, with a contract date of 1 October, 1980. A detailed and comprehensive program plan was submitted. The computer data bases CRIB and MILS were reviewed, and arrangements were made to purchase the tapes. A thorough review of data made available was conducted.

ACTIVITIES DURING THE REPORTING PERIOD

After considerable review of the data files from CRIB and MAS, it was concluded that CRIB is not as useful for this study as first thought, and efforts have been concentrated on working with MAS. The latest information and accessing programs are being obtained.

A draft of the General Mine Identification and Site-Specific Criteria have been submitted for ONWI review.

FUTURE ACTIVITIES

It is anticipated that all tasks will be completed during the next quarter except the Final Technical Report, which has been submitted.

ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AEGIS	Assessment of Effectiveness of Geologic Isolation Systems program (program replaces WISAP)
AESD	Advanced Energy Systems Division (Westinghouse)
AFR	away from reactor
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASTM	American Society for Testing Materials
BCD	Battelle Columbus Division
BCL	Battelle Columbus Laboratories
BEG	Bureau of Economic Geology (Texas)
BGI	Bechtel Group, Inc.
BLM	Bureau of Land Management, U.S. Department of the Interior
BNI	Bechtel National, Inc.
BNL	Brookhaven National Laboratory
BNW	Battelle-Northwest
BPMD	Battelle Project Management Division
BPNL	Battelle Pacific Northwest Laboratories
BWIP	Basalt Waste Isolation Project
BWR	boiling water reactor
CANDU	pressurized heavy water reactor (Canadian)
CFR	Code of Federal Regulations
Ci	Curie
CRRD	Conceptual Reference Repository Description
CSM	Colorado School of Mines (Golden, CO)
D/D; D&D	decontamination and decommissioning
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIS	environmental impact statement
EMAD	Engine Maintenance, Assembly, and Disassembly Facility
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
FR	Federal Register
FRG	Federal Republic of Germany
FY (TD)	fiscal year (to date)
GIR	Gulf Interior Region
GPM	Geologic Project Manager

HARC	Human Affairs Research Centers (Battelle-Seattle)
HEDL	Hanford Engineering Development Laboratory
HLW	high-level waste
HWR	heavy water reactor
IAEA	International Atomic Energy Agency
ILW	intermediate-level waste
IWG	Interface Working Group
KBS	Kärnbränslesäkerhet, Swedish Nuclear Fuel Supply Co., Safety Board Division
LASL	Los Alamos Scientific Laboratory
LATA	Los Alamos Technical Associates, Inc.
LBL	Lawrence Berkeley Laboratory
LETCo	Law Engineering Testing Company
LLL	Lawrence Livermore Laboratory
LLW	low-level waste
LSU	Louisiana State University
LVDT	linear variable differential transformer
LWR	light water reactor
MCC	Materials Characterization Center, Battelle, Richland
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NEA	Nuclear Energy Agency; National Energy Act
NEPA	National Environmental Policy Act; National Environmental Protection Agency
NOAA	National Oceanographic and Atmospheric Administration
NPO	NWTS Program Office (formerly RL-C)
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NUS	NUS Corp. (Nuclear Utilities Services Corporation)
NWTS	National Waste Terminal Storage (program)
ONI	Office of NWTS Integration
ONWI	Office of Nuclear Waste Isolation
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OWI	Office of Waste Isolation (predecessor of ONWI)
PNL	Pacific Northwest Laboratory (Battelle)
PSU	Pennsylvania State University
PWR	pressurized water reactor
QA	quality assurance

R&D	research and development
RHO	Rockwell Hanford Operations
RL-C	Richland Operations, Columbus Program Office, now NPO
SAC	Swedish-American Cooperative
SAI	Science Applications, Inc.
SCEPTER	Systematic Comprehensive Evaluation of Performance and Total Effectiveness of Repositories
SEM	scanning electron microscope
SF	spent fuel
SL	Sandia Laboratories
SRL	Savannah River Laboratory
SRP	Savannah River Plant
TBEG	Texas Bureau of Economic Geology
TRU	transuranic (contaminated) waste
USBM	U.S. Bureau of Mines
USGS	U.S. Geological Survey
WAES	WAESD, Westinghouse Advanced Energy Systems Division
WBS	Work Breakdown Structure
WES	Waterways Experiment Station, Corps of Engineers
WIPP	Waste Isolation Pilot Plant
WISAP	Waste Isolation Safety Assessment Program (replaced by AEGIS and WRIT)
WRIT	Waste-Rock Interactions technology program (program replaces WISAP)

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